MODIFICATION OF POLYMER FLOCCULANTS FOR THE REMOVAL OF SOLUBLE CONTAMINANTS FROM WATER

A Dissertation

by

TIMOTHY STEVEN O'GARA GOEBEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2010

Major Subject: Agronomy

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Approved by:

Chair of Committee,	Kevin McInnes
Committee Members,	Scott Senseman
	Sam Feagley
	David Zuberer
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ABSTRACT

Modification of Polymer Flocculants for the Removal of Soluble Contaminants from Water. (December 2010)

Timothy Steven O'Gara Goebel, B.S.; B.S., Texas Tech University;

M.S., Texas Tech University

Chair of Advisory Committee: Dr. Kevin McInnes

Contaminants in aqueous environments exist in phases that are sorbed to suspended or colloidal material and that are dissolved in solution. Polymer flocculants can be used to remove suspended or colloidal material along with sorbed contaminants, but they remove little of the dissolved contaminants. In the study presented here, development of polymers to sorb contaminants from aqueous solution during the flocculation process was investigated.

Atrazine and phosphate ($H_2PO_4^-$) were chosen as test contaminants. For a given test contaminant, multiple copies of a functional group that interacted with that contaminant were inserted into the polymer backbone of a polyacrylamide flocculant. The functional groups inserted into the polymer structure acted as a trap for the dissolved contaminant. The traps were a cyclic secondary amine that interacted with atrazine, and a thiourea that interacted with phosphate.

Modified flocculants with different configurations and densities of trapping groups were made and evaluated for removal of the test contaminants from aqueous

suspensions. The suspensions consisted of bentonite or kaolinite in water with a known concentration of a test contaminant. The atrazine source was labeled with ^{14}C and concentrations were measured using a scintillation counter. The source of phosphate used was NaH_2PO_4 and ion chromatography was used to measure the aqueous concentrations of phosphate.

In general, the modified polymer flocculants containing trapping groups removed significantly more atrazine and phosphate from suspension compared to the control polymer flocculants (α =0.05). While the amount of modified polymers needed to achieve significant removal of the test contaminant were higher than the Environmental Protection Agency limit for concentration of polyacrylamide flocculants in water, it was possible to enhance the polymers sorbtion and removal of contaminants from solution during the flocculation process.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. McInnes, and my committee members, Dr. Senseman, Dr. Zuberer, and Dr. Feagley, for their guidance and support throughout the course of this research. I would also like to thank Dr. Simanek and Dr. Hollink for their help developing the piperizine based polymers. In addition I would like to thank Dr. Davis for his help developing the thiourea based polymers. I would also like to thank Dr. Lascano for the use of his lab and facilities for the continuation of the research project.

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CHAPTER I

INTRODUCTION AND

LITERATURE REVIEW

Contaminants in water containing colloidal or suspended solids (hereafter referred to as suspended solids) can exist in sorbed or soluble phases. One method to remove sorbed contaminants from water is through flocculation followed by settling or filtration of the flocculated solids (1-4). Flocculation organizes smaller suspended solids into larger aggregates called flocs. Flocs settle quicker and are easier to filter than the unflocculated solids (1). Synthetic polymers are commonly used as flocculating agents (polymer flocculants) in water treatment facilities (3). Polymer flocculants currently used are effective at removing contaminants sorbed to suspended material, but not in removing soluble contaminants (1). By changing the affinity of the flocs for a soluble contaminant through modification of the flocculant, it may be possible to remove a portion of the soluble contaminants along with the contaminants sorbed to the suspended solids (Figure 1). Since polymer flocculants are widely used in water treatment, it should prove useful to remove additional amounts of an aqueous contaminant with a

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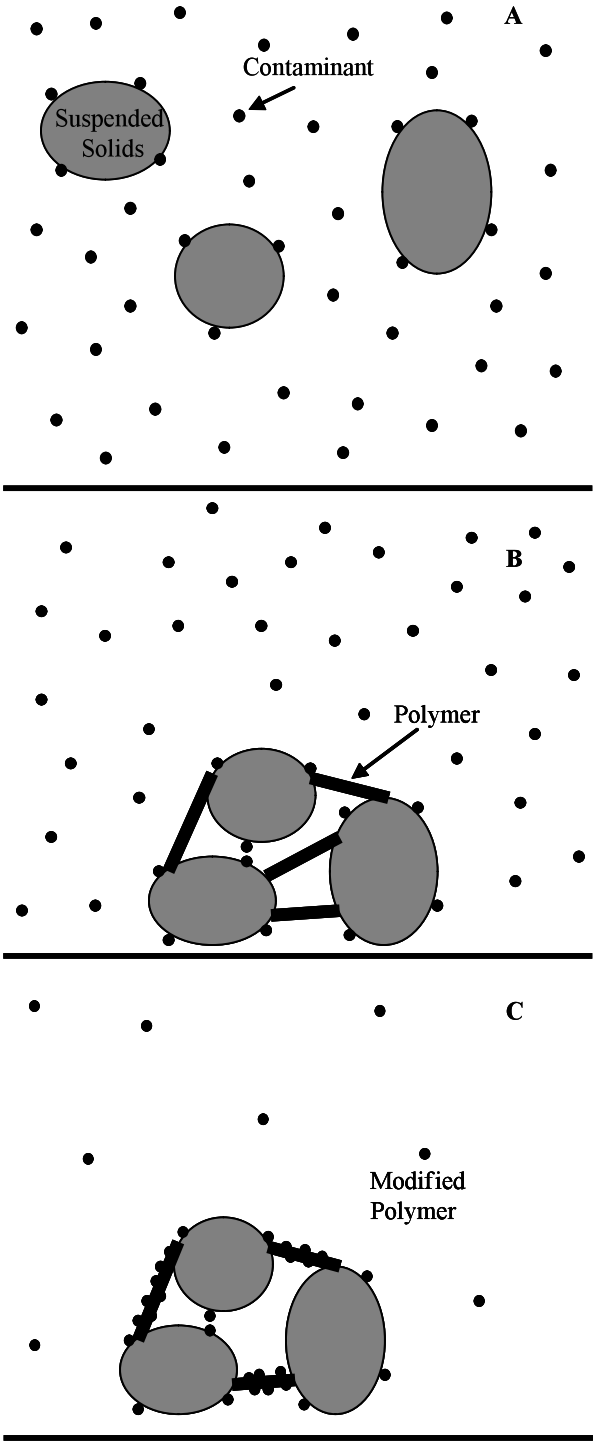

Figure 1. Conceptual model depicting the relative location of contaminants in solution prior to the addition of a polymer flocculant (a), after application of a polymer flocculant (b), and after the application of a polymer flocculant modified to sorb contaminants from solution (c).

modified polymer flocculant. In a municipal or industrial wastewater treatment setting, polymers modified to help remove soluble contaminants could reduce the cost treatment. In an agricultural setting, the use of modified flocculants could reduce the soluble contaminant load in runoff water from agricultural fields prior to its release into streams, rivers and lakes.

For a modified polymer to maintain its effectiveness as a flocculant, it must retain certain physical and chemical characteristics such as water solubility and net charge. Commercially available polymer flocculants are typically linear chains consisting of one or several monomer subunits (Figure 2), and generally categorized by their net charge, charge density, and molecular weight. Charge density is generally indicated by mole percent of charged groups. Polymer flocculants are quite large with molecular weights of $<10^5$, 10^5 to 10^6, and $>10^7$ g/mol considered to be low, medium and high molecular weight, respectively (5). When dissolved in water, polymer flocculants typically adopt random coil configurations (6). For high-molecular-weight polymers, the end-to-end length if stretched out would be roughly 10 μm. The diameter of the random coil is dependent on the charge density of the polymer, but generally is about 60 nm (6).

There are several stages in the removal of suspended solids using polymer flocculants (Figure 3): addition of the polymer flocculant to the suspension, mixing, adsorption of the polymer to the suspended solids, rearrangement of adsorbed chains on the solids, and flocculation (5). Polymer flocculants generally are added to suspensions

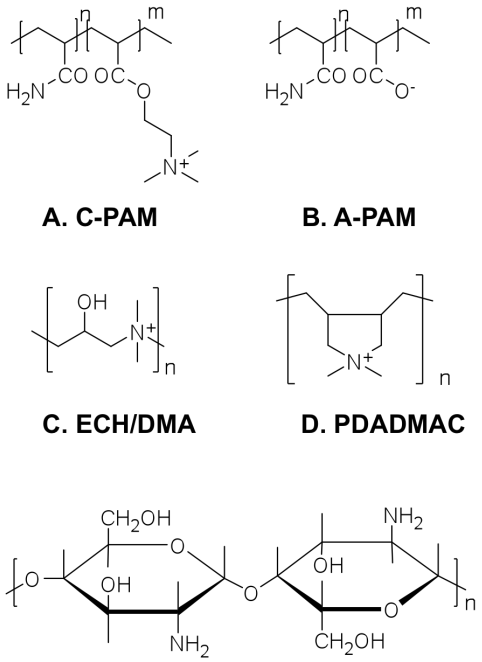

Figure 2. Chemical structures of some common polymer flocculants.
A) Cationic Polyacrylamide; B) Anionic Polyacrylamide;
C) Epichlorohydrin/ Dimethylamine; D) Polydiallyl Dimethyl Ammonium Chloride; E) Poly-(1-4)-2-Amino-2-deoxy-β-D-Glucan.

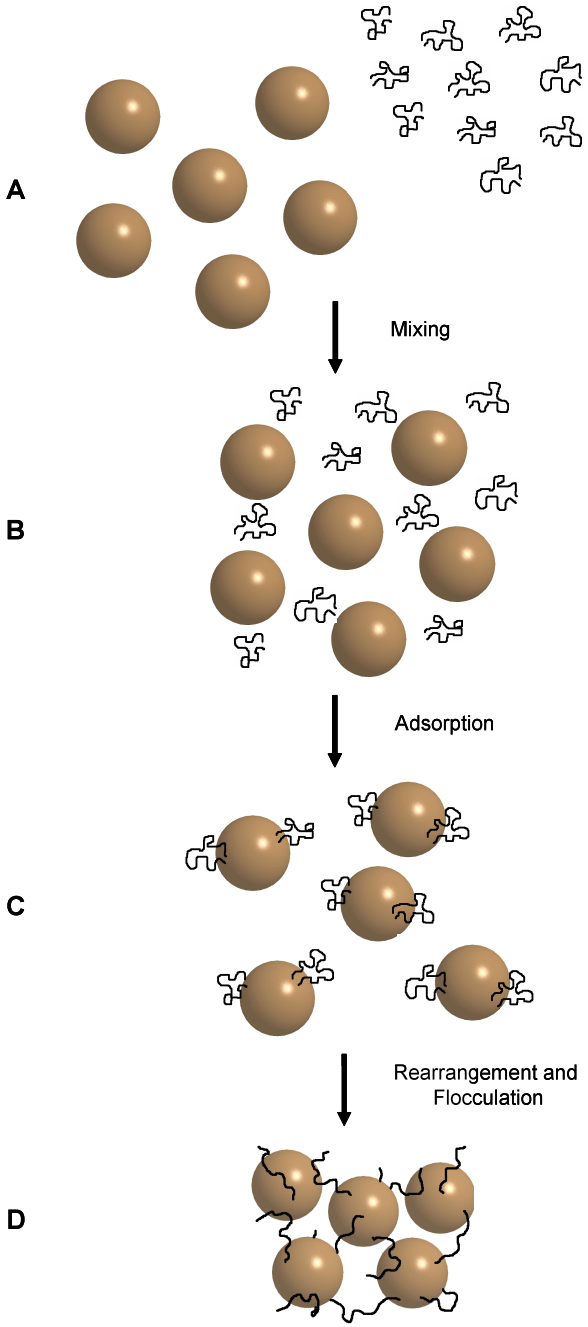

Figure 3. Stages of flocculation. A. Mixing; B. Adsorption; C. Rearrangement; D. Flocculation.

as concentrated solutions. Solutions with high polymer concentrations are viscous and would not readily disperse without mixing. During mixing the polymers begin to sorb to the surface of the suspended solids. Adsorption of the polymer to the solids is a second-order reaction, the rate being proportional to the concentrations of the solids in solution and the polymer (7).

When low molecular weight polymers are used, the rate of adsorption of the polymer flocculant to the suspended solid is controlled by diffusion of the polymer to the solid surface (5). Since diffusion controls the rate of interaction between small molecular weight polymers and suspended solids, physical mixing of the solution containing the polymer flocculant and suspended solids has less effect on the adsorption of small molecular weight polymers. If high molecular weight polymers are used, diffusion plays a minor role and physical mixing of the solution containing the polymer and suspended solids is necessary to efficiently develop flocs (5). When high molecular weight polymers are used, the rate of adsorption of the polymer to the surface of the suspended solid is controlled by how vigorous the polymer and suspension are mixed. Once the polymer has at least one point of its coil anchored to a particle, a portion of the remaining chain sorbs to the surface forming features referred to as loops, tails, and trains (Figure 4) (6). The formation of the loops, tails, and trains takes several seconds. During that time, bridging between particles begins. Loops and tails extending away from the surfaces are sites available to continue to interact with solids in suspension.

Sorption of loops and tails to other particles causes bridging (5). As bridging becomes more extensive large aggregations called flocs are formed. The flocs then separate from suspension and can be removed by settling or filtration. The entire flocculation process can be completed in minutes (7).

For a modified polymer to be efficient at removing soluble contaminants it should interact with the soluble contaminants prior to the settling of the flocs. During the formation of flocs, both the contaminants and the modified polymer would be in close proximity and the rate of their interaction would be the highest. Once the flocs have settled, contaminants left in solution would have to reach the settled flocs to interact with the modified polymer. In time, the concentration of the contaminant in solution would decrease as the contaminant continues to sorb to the settled modified polymer.

Successful development of a polymer flocculant that would interact with a contaminant in solution would require modification of the polymer with the addition of multiple copies of a small molecule (hereafter referred to as a trapping group) to the polymer chain. The trapping group could be added to a polymer flocculant by several methods. One method to develop a modified polymer would be to add the trapping group to either the ends or along the chain of an existing polymer flocculant. Another method of adding the trapping group would be to co-polymerize a monomer containing the trapping group along with the monomers of the polymer flocculant. Either method would require the selection of an effective trapping group. When choosing a trapping group, the effect of that trapping group on the properties of the polymer must be

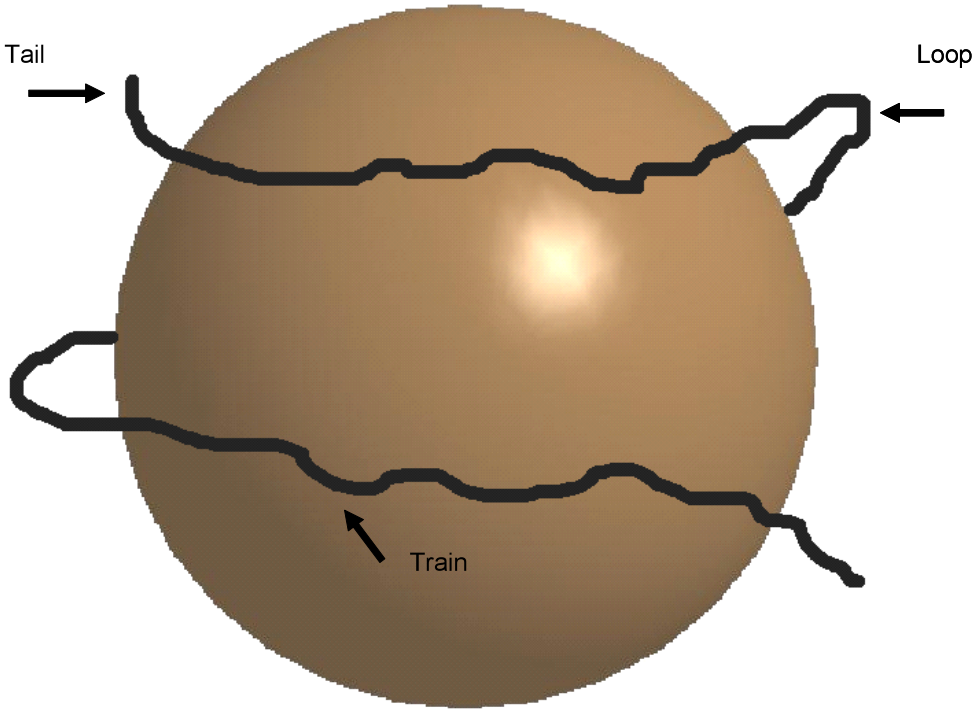

Figure 4. Illustration of polymer interacting with the surface of a particle in trains attached to the surface, and loops and tails extending away from the surface.

considered. For the polymer to remain an effective flocculant, the addition of the trapping group must not drastically change the water solubility or net charge of the polymer.

Cationic polyacrylamides are copolymers consisting of two monomer units: acrylamide and acryloxyethyltrimethyl-ammonium chloride (Figure 5). The charge density of cationic polyacrylamides can be adjusted by changing the amount of acryloxyethyltrimethyl-ammonium chloride added to the polymerization accompanied by adjustment of an equimolar amount of the acrylamide. Since it is possible to remove some portion of acrylamide and replace it with acryloxyethyltrimethyl-ammonium chloride then it might also be possible to replace the acrlyamide with an equimolar amount of the trapping group (Figure 5). The addition of the trapping group in this manner would maintain the charge density of the of the polymer flocculant while adding the function of the trapping group to the polymer.

The goal of the study reported in this dissertation was to design and build polymer flocculants that would sorb contaminants from the soluble phase. There were numerous aqueous contaminants that could have been used as test compounds, and for each of the contaminants there likely would have been several functional groups that would serve as a trapping group. Two chemicals that have been widely recognized as contaminants of surface waters are atrazine and phosphate. Atrazine is a pesticide used to control broadleaf weeds in grass crops such as corn and sorghum, and has been found in surface and ground water (8-11). Phosphorus is an essential plant nutrient that is

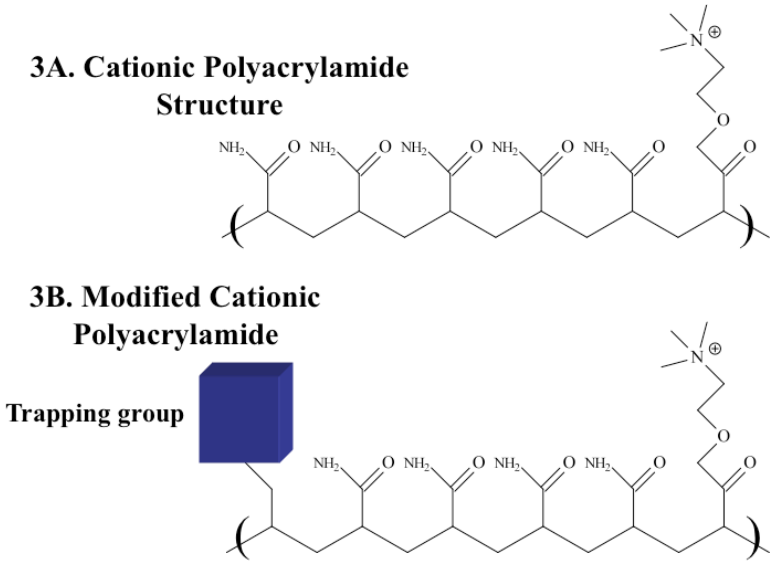

Figure 5. A) Example of a cationic polyacrylamide. B) General example of modification of a cationic polyacrylamide.

applied as a fertilizer and is frequently found in surface water (12-16). Both atrazine and phosphorus partition between soluble and sorbed phases. The two test contaminants offered the opportunity to evaluate the possibility of creating a polymer flocculant that served the removal of both aqueous and sorbed contaminants from water. Two functional groups known to interact with the two contaminants were chosen. The two functional groups utilize different bonding mechanisms to interact with the respective contaminant. The different bonding mechanisms likely affect the kinetics, reversibility, and selectivity of the reaction of the trapping group with the contaminant as well as the suspended solids. Kinetics, reversibility, and selectivity of the reactions would be important factors governing whether the modified polymer would function as desired.

A water insoluble polymer containing the cyclic secondary amine, piperizine, removed >98% of atrazine from solution (17). Since the polymer was not water soluble it would not function as a polymer flocculant, however the study presented the possibility of using a similar cyclic secondary amine molecule to develop a modified polymer flocculant.

Thiourea incorporated into a water insoluble polymer selectively removed phosphate from solution (18). While the insoluble polymer would not function as a polymer flocculant, the results from the study suggest it might be possible to use thiourea to modify a polymer flocculant to selectively trap and remove phosphate from solution.

CHAPTER II

MODIFICATION OF POLYMER FLOCCULANTS FOR THE REMOVAL OF SOLUBLE CONTAMINANTS FROM WATER USING ATRAZINE AS THE TEST CONTAMINANT

Introduction

Atrazine is an herbicide used to control broadleaf weeds in grass crops such as corn and sorghum, and it has been found as a contaminant of surface and ground water (8-10). Recently, a polymer containing a cyclic secondary amine was demonstrated to interact with atrazine (17). The addition of the cyclic secondary amine to the backbone of a polymer flocculant might create a flocculant that would sorb atrazine from solution.

To create a modified flocculant containing the cyclic secondary amine and to have that flocculant be useful in a practical setting, several potential obstacles were considered. The modification must result in a water-soluble polymer. Since the cyclic secondary amine group was reasonably water-soluble the resulting polymer should be water-soluble. Another possible problem was that the polymer flocculant might bind to the suspended solids with a high enough affinity that the cyclic secondary amine groups would be restricted from interacting with the contaminants in solution. Polymer flocculants sorbed to suspended solids form loops and tails that extend into solution and interact with other suspended solids to form flocs. The portion of polymer that extends into solution between two or more particles forms a bridge. The cyclic secondary amine group present in a bridge would extend through bulk solution and interact with the

contaminant. Should a majority of the polymer be sorbed on the surface of the suspended solids and not exist in the bridges, a high density of the cyclic secondary amine on the polymer might be required to result in a quantity of the cyclic secondary amine on the bridges large enough to result in significant removal of atrazine from solution. A high density of the cyclic secondary amine on the polymer would increase the amount present on the bridge and would increase the sorption efficiency of the polymer.

Materials and Methods

Synthesis

A modified polyacrylamide flocculant was synthesized following the scheme presented in Figure 6. The first step of the synthesis was to make the cyclic secondary amine trapping group into a monomer form that would polymerize along with the acrylamide and acryloxyethyltrimethyl-ammonium chloride. In the final step, polymerization produced a polymer consisting of three monomer units dominated by acrylamide and trimethyl ammonium monomers. In addition, a nonionic polymer was made without the addition of the trimethyl ammonium monomer. The modified polymers were made and characterized by NMR (Appendix A).

Synthesis of 4-aminomethyl-piperidine-1-carboxylic acid tert-butyl ester

Two g of 4-aminomethyl piperizine (4-AMP), and 1.8 g of triethylamine were dissolved in 35 mL of dichloromethane (DCM) and placed in an ice bath until the temperature was

0 °C. To the stirring solution, ethyl trifluoro acetate (2.612g in 10 mL of DCM) was added drop wise. The solution was stirred for 30 min at 0 °C, then it was left to come to room temperature and react for 1 h. tert-butyl carbamate (Boc) (4.014 g) in 10 mL DCM was then added drop wise and the resulting solution was stirred for 5 h. The solvent was removed in vacuo and the resulting yellow oil was dissolved in 250 mL ethanol (EtOH). NaOH (26.016 g in 215 mL H_2O) was then added to the solution. The reaction was stirred for 6 h. The EtOH was removed in vacuo and the water was extracted three times with 30 mL of DCM. The water was removed from DCM with $MgSO_4$ and the solvent was removed in vacuo resulting in colorless oil. (13.48 g, 71.8% yield).

Synthesis of 4-(acryloylamino-methyl)-piperidine-a-carboxylic acid tert-butyl ester

Triethyl amine (3.153 g) was added to an ice-cooled solution of 4-aminomethyl-piperidine-1-carboxylic acid tert-butyl ester (5 g) in 200 mL of tetrahydrofuran (THF) and stirred for 30 min. 1-chloroacetate (3.152 g in 100 mL THF) was added drop wise to the stirring solution. Upon completion of the dropwise addition, the mixture was allowed to come to room temperature and react for 5 h. A precipitate that formed was removed by filtration and the THF was removed in vacuo. The resulting oil was dissolved in DCM and was washed 3 times with $NaHCO_3$, dried with $MgSO_4$, and the DCM was removed in vacuo. The reaction produced a pale yellow oil which was considered pure by NMR and used in the next step (5.28 g, 84.4% yield).

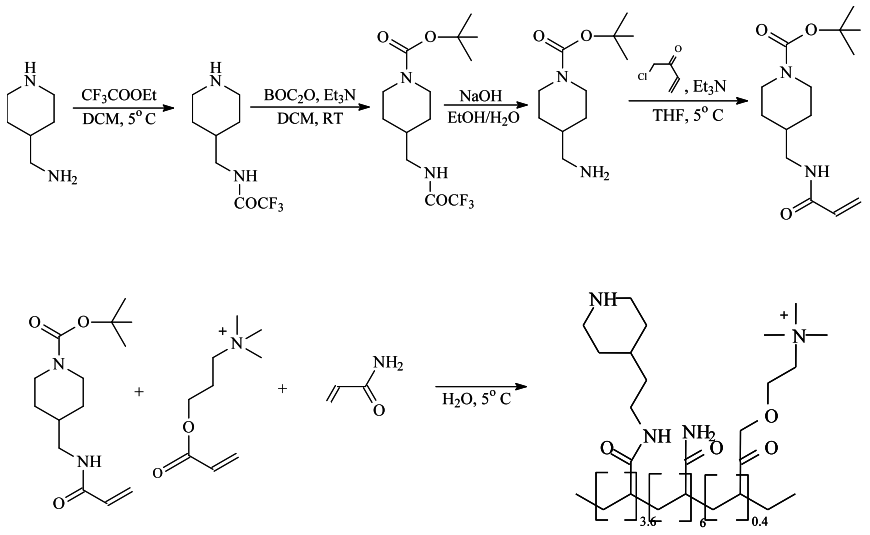

Figure 6. Scheme for the synthesis of a modified cationic polyacrylamide.

Synthesis of a cationic polymer flocculant

A cationic acrylamide copolymer was prepared by gel polymerization similar to U.S. patent 5,945,494. To prepare the monomers for polymerization, 8.997 g of acrylamide, 16.365 g of 80% acryloxyethyltrimethyl-ammonium chloride, 0.226 g of 4-(acryloylamino-methyl)-piperidine-a-carboxylic acid tert-butyl ester, 0.002 g of 10% diethylenetriamine-pentaacetate (pentasodium salt), 1.5 g adiptic acid, 0.11 mL of 20% sulfuric acid, 0.003 g of 1% sodium hypophosphite (100 mg/L on monomer), 0.003 g of methylene bisacrylamide were dissolved in 41.233 g deionized water. The solution was sparged with nitrogen gas for 30 min. During sparging, the solution temperature was adjusted to 6 °C. After sparging, 1 mL of 2% 2,2-azobis(2-methyl-2-amidinopropane) dihydrochloride, 80 μL of 0.25% ammonium persulfate and 80 μL of 0.25% ferrous ammonium sulfate hexahydrate polymerization activators were added. When the monomer mixture thickened, the nitrogen sparge tube was raised to the top of the polymerization vessel. The polymerization reaction was exothermic and reached a maximum temperature of 30.5 °C at which time it was placed in an oven set at 70 °C for 8 h. The resulting gel was reduced to coarse powder by grinding in a mortar and pestle to a diameter passing a 1.2-mm sieve. The nonionic polymers were made following the same procedure without the addition of the trimethyl ammonium monomer, substituting an equimolar amount of acrylamide to compensate for the missing trimethyl ammonium monomer.

The nomenclature used to describe the polymers that were prepared is as follows: “C” represents cationic polymer, “N” represents nonionic polymer, the number

following represents the mole percentage of positive charge on the polymer, and the number following the second hyphen represents the mole percentage of the trapping group (Table 1). For example, C-40-0.4 represents a cationic polymer with 40 mole percent of positive charge and 0.4 mole percent of the trapping group. Magnifloc 495C (10% positive charge)and Magnifloc 700N (0% positive charge) were also used as control polymers for polymer flocculants currently commercially available from Cytex.

Table 1. Mole percent of monomers for individual polymers.

Monomer	**C-40-00**	**C-40-0.4**	**C-40-04**	**N-00-00**	**N-00-0.4**	**N-00-04**
acrylamide	59.99	59.73	57.66	99.99	99.60	96.14
Trimethyl ammonium chloride	39.99	39.87	38.48			
piperazine acrylate		0.40	3.86		0.40	3.86
diethylene triamine	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
methylene bisacrylamide	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Polymer Sorption

Once the modified polymer flocculants were prepared, a set of experiments was conducted to test the sorption of atrazine to the polymer. To test the modified polymers removal of sorbed and soluble atrazine, a clay-water suspension containing ^{14}C-labeled atrazine at a concentration of 2 mg/L was created. The 2 mg/L concentration of atrazine was higher than that found in most environmental conditions, but similar to that reported in the study by Acosta *et al* (17).

The suspension contained 20 mg of Gonzalez bentonite in 4 mL of water and was allowed to swell overnight to minimize atrazine sorption. To the suspended solids containing the ^{14}C-labeled atrazine, 4.5 mg of the polymers in 1 mL of water was added and the suspension was shaken for 24 h. The suspensions were centrifuged using a Fisher Scientific model 225 centrifuge with an R8 head at a speed setting of 6 for 20 min and two aliquots of the supernatant from each replicate were tested for atrazine using a scintillation counter. The experiments were run in triplicate. A decrease in the aqueous phase atrazine concentration from the control containing only atrazine was assumed to be caused by sorption to bentonite and sorption to the polymer. To determine the amount of atrazine removed by the polymers, a control using only bentonite in water with atrazine was used to obtain an average amount of atrazine removed by bentonite. The amount of atrazine removed by bentonite was subtracted from the total amount of atrazine removed from solution to estimate the amount of atrazine removed by the polymer flocculants.

A test of the modified polymers under concentrations more likely found under field-conditions was conducted (10). The procedure above was followed but amended by lowering the atrazine concentration to 20 μg/L. Since the concentration of atrazine had little effect on the removal of atrazine from solution, the interaction time needed for removal of atrazine from solution was tested. The procedure above was followed except for the amount of time that the polymer was allowed to interact with the suspension. The amount of time that the polymer-clay suspension was shaken was: 1, 4, 12, or 24h. A final experiment was conducted to test the effect that decreasing the concentration of polymer had on the amount of atrazine removed from the aqueous phase. The polymer concentrations included were 1000, 500, 100, 50 and 10 mg/L. All the results were processed using R Stats software to determine confidence intervals at 95%.

Results and Discussion

The addition of the cyclic secondary amine to the polymer resulted in an increase in atrazine removed from suspension when the polymer was used to remove suspended solids (Figure 7). Increasing the density of the cyclic secondary amine from 0.4 to 4.0% on the polymer enhanced atrazine removal from suspension by the polymer (Figure 7). The results from the addition of unmodified control cationic polymer flocculants suggest

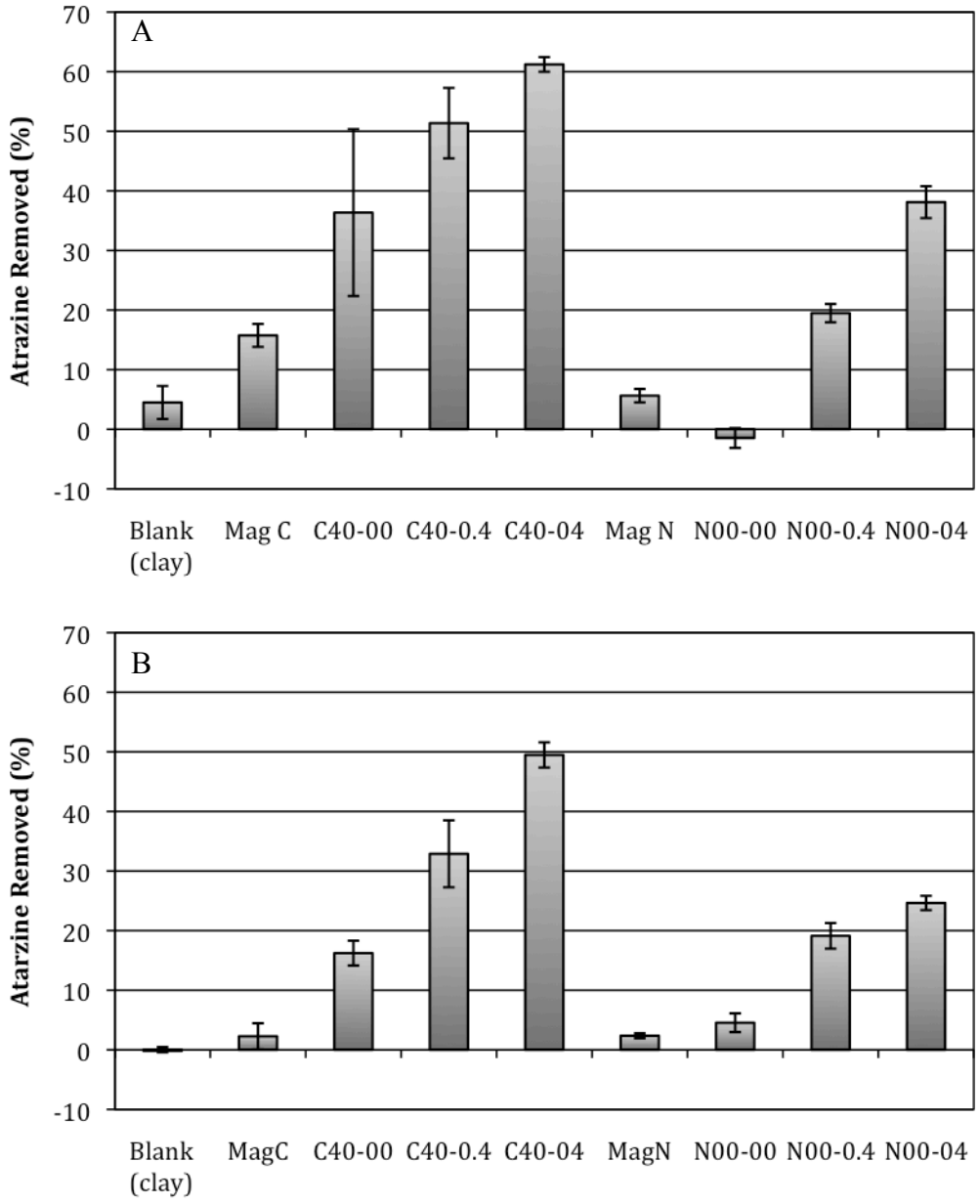

Figure 7. Amount of atrazine removed from suspension with two initial concentrations of atrazine of 2mg/L (A) and 20μg/L (B).

that the quaternary ammonium group on the polymer had some affinity for atrazine compared to the control nonionic polymer flocculants. The removal of atrazine from the aqueous phase by the polymers was reduced when the atrazine concentration was reduced from 2 mg/L to 20 μg/L likely due to dilution (Figure 7).

To determine the effect of time on the sorption of atrazine by the polymers the experimental conditions were maintained except the experiments were terminated at 1, 4, 12 and 24 h. The modified polymers removed significantly more atrazine from the aqueous phase compared to the control polymers when the amount of time was adjusted from 1h to 24 h (Figure 8). At 1 h the amount of atrazine in solution decreased with the addition of both unmodified control polymers, Magnifloc 494C and Magnifloc 700N (Figure 8). At 4 h the amount of atrazine in solution increased compared to the results at 1 h for the unmodified control polymers. The decrease in sorption of atrazine to the polymer with time suggests that the interaction of atrazine with the unmodified polymers can be affected by other variables present in the experiment. Atrazine is relatively hydrophobic with a solubility of 33mg/L and would partition into environments less polar than water such as the unmodified polymer. The results indicate that atrazine can repartition back into solution with time. The repartitioning of atrazine back into the aqueous phase was possibly due to continued rearrangement of the polymer on the surface of the solids. The continued rearrangement might occur as the polymer finds a conformation that is at it's lowest energy. The rearrangement of the polymer on the solid surface might increase the amount of the trimethyl ammonium groups interacting with the solid surface, decreasing the amount those groups left to interact with atrazine.

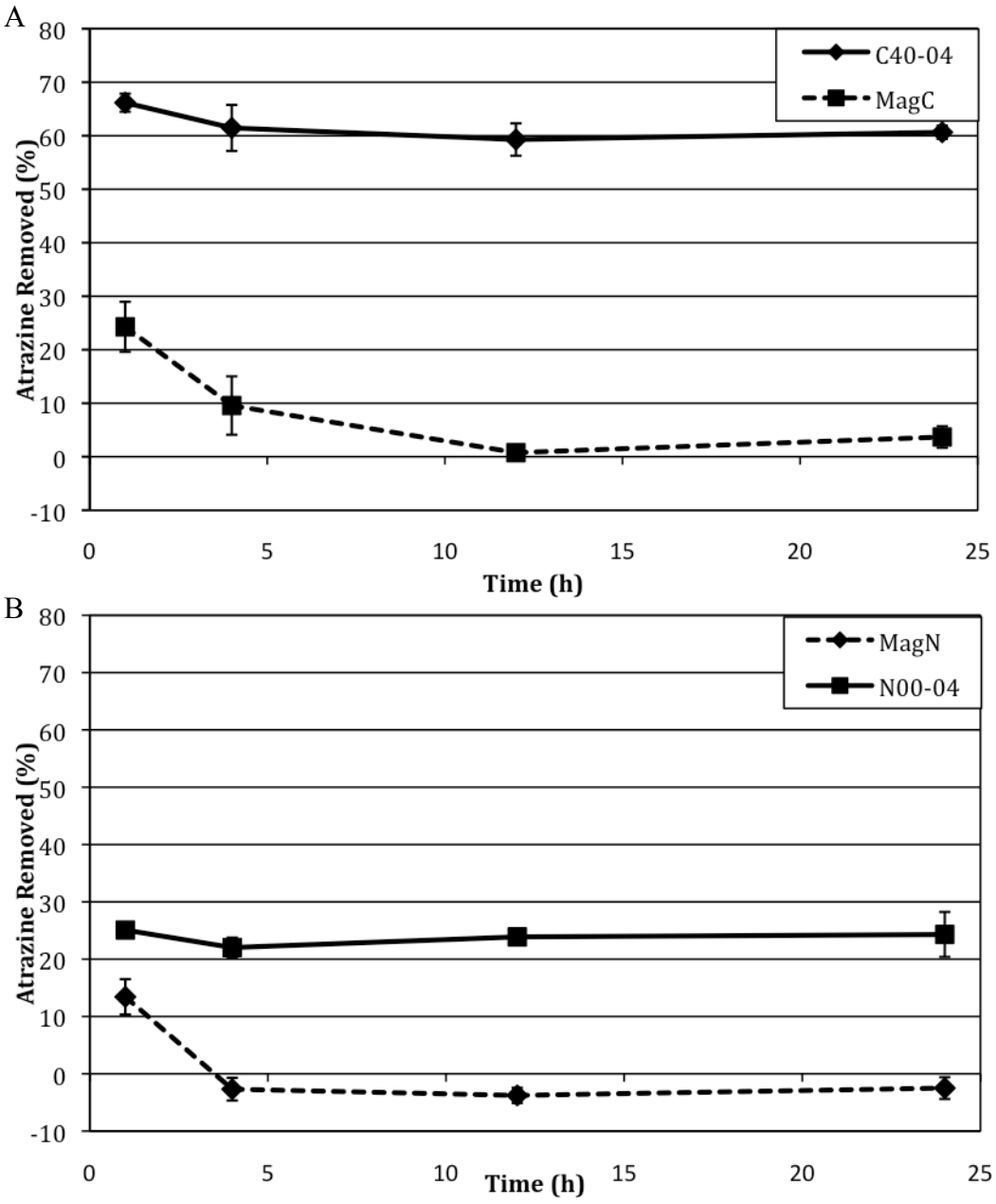

Figure 8. Atrazine removed from suspension by cationic (A) and nonionic (B) polymers over a 24-hour period.

The modified cationic polymer C40-04 retained its interaction with atrazine over the 24-h period suggesting an irreversible interaction of the modified polymer with atrazine. The interaction of atrazine with the cyclic secondary amine was not affected by further rearrangement of the polymer on the surface of the solids present, if it occurred.

Having examined the effect of atrazine concentration and time, the next variable that was changed was the polymer concentration. When the final concentration of the polymer flocculant in solution decreased from 1 g/L to 0.5 g/L with a constant amount of solid material present, the amount of atrazine removed from solution decreased from 60% to less than 10% of the initial 2mg/L concentration (Figure 9). The decline in the amount of atrazine removed from suspension indicates that a large amount of the polymer (1 mg/L) was needed to remove an appreciable amount of atrazine from solution. The amount of polymer needed to achieve significant removal of atrazine from the aqueous phase was 1 g/L, likely due to the low density of the cyclic secondary amine on the polymer. The solubility of the cyclic secondary amine monomer in water was low and polymerization with the other monomers was not possible at higher densities of the cyclic secondary amine.

The observations made in the study presented here suggest that it is possible to modify polymer flocculants to increase sorption of the test contaminant atrazine from aqueous phase and remove the sorbed atrazine from solution through flocculation. With a starting concentration of 2 mg/L of atrazine, the addition of modified cationic polymer C 40-04 to suspension decreased the atrazine concentration in solution by approximately

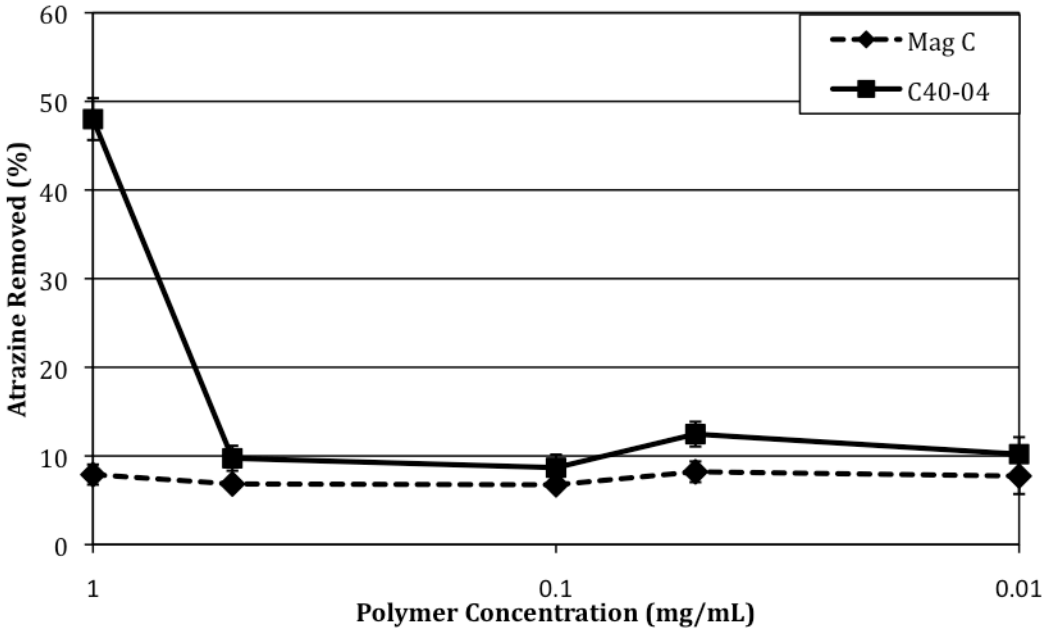

Figure 9. Effect of decreasing polymer concentration on atrazine removed from suspension.

45% compared to the commercially available Magnifloc 495C. The addition of C 40-04 decreased the atrazine concentration in solution by 30% compared to the unmodified cationic polymer C 40-00 (Figure 7). The data also revealed that increasing the density of the cyclic secondary amine on the polymer from 0.4 to 4.0% increased the amount of removed from solution in both the cationic as well as the nonionic polymers.

Generally, the additional amount of atrazine removed from solution by the addition of cationic modified polymer flocculants compared to the nonionic modified polymer flocculants represented the amount of atrazine removed by the positively charged quaternary ammonium ion as suggested by the results from the control polymer C40-00 (Figure 7). The similarity in the amount of atrazine removed from the aqueous phase by the addition of modified cationic and nonionic polymers indicates that the polymer backbone does not affect the interaction of the cyclic secondary amine with atrazine.

Even in more dilute concentrations of atrazine (20 μg/L) the modified polymers were effective at reducing the amount of atrazine in solution when the polymers were added at 1 g/L. Observations from the experiments conducted indicate that it is possible to use flocculation as a technique that can reduce contaminant concentrations in aqueous solutions. While polyacrylamides were chosen as the backbone for the modified polymers, due to concerns about contamination of the environment with acrylamides, other polymer flocculants such as: polydiallyl dimethyl ammonium chloride (polyDADMAC), epichlorohydrin/ dimethylamine (ECH/DMA), or chitosan could be utilized as the polymer backbone.

CHAPTER III

MODIFICATION OF POLYMER FLOCCULANTS FOR THE REMOVAL OF SOLUBLE CONTAMINANTS FROM WATER USING PHOSPHATE AS A TEST CONTAMINANT

Introduction

Phosphorus is an essential plant nutrient that is commonly applied as a fertilizer and is frequently found in surface water (12-16). It was recently demonstrated that a polymer containing thiourea groups sorbed phosphate from aqueous solution (18). The polymer was not water soluble, but was packed in a column and contaminated water was forced through the packed column. The thiourea groups were suggested to have a 4-point interaction with phosphate and the interaction maintained 75% selectivity for phosphate in the presence of equimolar concentrations of competing anions (18). While it is not possible to make a molecularly imprinted polymer flocculant, single thiourea molecules that interact with organophosphates in 2-point and 3-point hydrogen bonding systems have been developed (19-21). Thiourea is a small functional group that could be prepared as a monomer to polymerize with other monomers present in polymer flocculants. A polymer flocculant modified to contain thiourea should sorb or trap phosphate selectively to the polymer.

The thiourea molecules used for the preparation of the modified polymer flocculants were not water-soluble so their addition to the polymer at high densities resulted in polymers that were water insoluble. At lower densities of thiourea on the polymer the net polarity of the polymer was sufficient for water solubility. Another

possible problem was that the polymer flocculant might bind to the suspended solids so tightly that the thiourea would not be available to interact with the contaminants in bulk solution. Flocs are formed by polymer flocculants through sorption of the polymer to suspended particles (7). Some of the sorbed polymer forms loops and tails that extend into solution to form a bridge with other suspended particles to form flocs (3). Inserting the thiourea group into the polymer at 4% would likely lead to similar results as the cyclic secondary amine with atrazine. In this study, the thiourea group would be added at densities as high as solubility would allow.

Materials and Methods

Synthesis of Thiourea Based Polymers

To a stirring solution of 40 ml acetonitrile was added: 4.0 g (0.0206 mol) of 2-pt thiourea, 2.982 g (0.0412 mol) acrylamide, and 8.458 g (0.0412 mol) acryloxyethyltrimethyl-ammonium chloride. The solution was then sparged with nitrogen for 1 h, while the temperature was raised from room temperature to 30 °C. To a stirring solution, 0.169 g (1.03×10^{-3} mol) azobisisobutyronitrile (AIBN) was added to initiate polymerization. The reaction temperature peaked at 38 °C. The reaction was then heated to 50 °C and allowed to react for 16 h. The reaction produced a slightly yellow solid that was ground in a mortar and pestle to a 1.2-mm diameter powder and analyzed by NMR (Appendix B). Other polymers with different densities and a different thiourea molecule were made using the same methods changing the mole percentage of monomers.

The nomenclature used to describe the polymers is as follows: “C” represents cationic polymer, the number following represents the mole percent of positive charge on the polymer, and the number following the second hyphen represents the mole percent of the thiourea group with 2pt or 3pt indicating which thiourea was used (table 2). For example, C-40-20 (2pt) represents a cationic polymer with 40% positive charge density and 20% density of the 2-point thiourea and 40% density of acrylamide. Magnifloc 494C and Magnifloc 700N were also used as control polymers for polymer flocculants currently commercially available.

Table 2. Mole percent of monomers for individual modified polymers.

Monomer	**C-40-00**	**C-40-20 (2pt)**	**C-40-40 (2pt)**	**C-40-20 (3pt)**
acrylamide	60	40	20	40
Trimethyl ammonium chloride	40	40	40	40
Thiourea (2pt)	N/A	20	40	N/A
Thiourea (3pt)	N/A	N/A	N/A	20

Polymer Sorption Tests

Once the modified polymers were prepared, experiments were conducted to test the sorption of phosphate to the polymer and the selectivity of the sorption in the presence of other anions. To create an aqueous suspension, bentonite or kaolinite were

weighed and added to a known volume of water. Phosphate was then added from an intermediate standard to create an aqueous suspension with a known phosphate concentration.

Controls containing phosphate and clay were tested to check the level of sorption of phosphate to the clay used. Several different polymers were tested for an interaction with phosphate. Magnifloc 700N was tested as a control having 100% acrylamide with no positive charge density. Magnifloc 494C was tested as a control with 10% positive charge density and 90% acrylamide. The polymer C40-00 was made according to U.S. patent 5,945,494 as a control with 40% positive charge density and 60% acrylamide, C40-20(2pt) was made with 40% positive charge density, 20% 2 point thiourea (Figure 10A), and 40% acrylamide. C40-40(2pt) was made with 40% positive charge density, 40% 2 point thiourea (Figure 10A), and 20% acrylamide. C40-20(3pt) was made with 40% positive charge density, 20% three point thiourea (Figure 10B), and 40% acrylamide.

To determine the polymers sorption of phosphate from solution several variables had to be examined, including: the concentration of polymer, the concentration of phosphate and the amount of time required to achieve an appreciable removal of phosphate from water. Once the effects of the variables were understood, a study was conducted to test ability if the polymers to maintain the amount of phosphate removed in the presence of other anions.

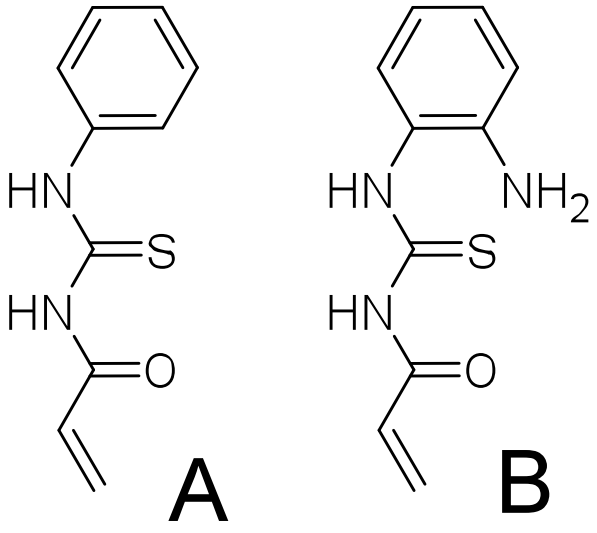

Figure 10. Structures of thiourea monomers used as trapping groups. One having a suggested 2-point hydrogen bonding interaction (A) and the other having a 3-point interaction (B).

Two main studies were conducted to test the modified polymer flocculants. The goal of the first study (Study 1-1 to Study 1-3) was to use equimolar concentrations of NaH_2PO_4, NaF, NaCl, NaBr, $NaNO_2$ and $NaNO_3$ to test the selectivity of the thiourea molecule on the polymer for phosphate sorption. The goal of the second study (Study 2-1 to Study 2-3) was to use anion concentrations similar to wastewater to test the selectivity of the thiourea molecule for phosphate sorption. To conduct the two studies, several experimental conditions had to be determined. Variables in the experiment included the amount of polymer added, the amount of phosphate to be added, the amount of time the polymers were left to interact with phosphate in suspension, the amount of suspended solid material used, the type of suspended solid material used, and whether samples would be taken for analysis after the resulting flocs had settled or after shaking the suspension for a set amount of time. Table 3 lists the experiments conducted for each study.

Study 1.1 consisted of a 25 mg/L polymer concentration and several different phosphate concentrations to determine at what phosphate concentration range the polymers would remove a significant portion of phosphate from solution. The polymers were tested for sorption of phosphate by adding the polymer to a suspension containing a known amount of phosphate and clay. Clay suspensions were produced by the addition of 125 mg of a Gonzalez Bentonite that had no detectable phosphate associated with it to a test tube containing 19 mL of ultrapure water. Suspensions were allowed to hydrate overnight. To the clay suspension was added 0.5 mL of the phosphate intermediate

Table 3. Experimental conditions for Study 1 and Study 2.

	Polymer concentration (mg/L)	Phosphate concentration (mg/L)	Time (h)	Solid material added (mg)	Type of solid material	Continuous agitation (Y/N)	Competitive Anions
Study 1.1	25	5, 1, 0.5, 0.25	1/3	125	bentonite	No	Phosphate only
Study 1.2	25	0.5	1/3	125	bentonite	No	Equimolar concentrations
Study 1.3	25	0.5	1/3,2,12, 24	125	bentonite	No	Equimolar concentrations
Study 2.1	100	1,5	12	500	bentonite	Yes	Phosphate only
Study 2.2	100	1,5	12	500,250, 100	kaolinite	Yes	Phosphate only
Study 2.3	100	5	12	250	kaolinite	Yes	Simulated wastewater

standard to give final concentrations of 5, 1, 0.5 and 0.25 mg/L phosphate. The test tubes were then vortexed for 5 seconds. Following mixing, 0.5 mL of the polymer intermediate standard was added to give a final concentration of 25 mg/L of the polymer. The resulting suspensions were vortexed for 5 seconds and allowed to settle for 20 min. A 5mL aliquot was then taken from the supernatant and the solids were separated using a Fisher Scientific model 225 centrifuge at 305 g for 10 min. A 2-mL sample was then filtered through a 2 μm filter and analyzed by ion chromatography.

Polymers were tested for phosphate selectivity in the presence of other anions (Study 1.2). The method above was followed, but with the addition of equimolar concentrations of NaH_2PO_4, NaF, NaCl, NaBr, $NaNO_2$ and $NaNO_3$, to give a final concentration in the test tube of 8.33×10^{-4} mol/L of each of the anions. The polymers were then added to the suspension of clay and anions, and the procedure described above was followed.

The effect of time was tested on the amount of phosphate removed from suspension (Study 1.3). In a time-course experiment, the procedure for the competition study was followed with the exception that the suspensions were allowed to settle for 20 min, 2 h, 12 h and 24 h before the 5 mL aliquot was taken from the supernatant and analyzed.

Using the results from Study 1, Study 2 was conducted. The goal of the experiments in Study 2 was to determine the optimal conditions needed for removal of phosphate from the aqueous phase with addition of the polymers. The optimal conditions could then be used to determine selectivity of the polymers for phosphate in the presence of anions at concentrations similar to wastewater.

Another study (Study 2.1) was conducted to determine the optimal conditions for the removal of phosphate by the polymers. Based on the observations when atrazine was the test contaminant, it had been established that increasing the polymer concentration and agitating the resulting polymer-solids mixture would increase the amount of contaminant removed from suspension. Using that information, the concentration of the polymers was increased from 25 to 100 mg/L and the resulting polymer-phosphate-solids mixture was shaken for 12 h. The phosphate concentrations used were 1 and 5 mg/L. To ensure that some of the polymer was not left free in solution after flocculation, the amount of clay added was increased to 500 mg to compensate for the increase in polymer concentration.

The following experiment (Study 2.2), substituted kaolinite to alter the material representing the suspended solids. The polymer concentrations were held at 100 mg/L. Phosphate concentrations of 1 and 5 mg/L were used. The clay concentrations were varied using 500 mg, 250 mg, and 100 mg of kaolinite. The suspensions were again shaken for 12 h centrifuged and analyzed as described above.

Based on the results from all of the experiments above, optimal conditions were chosen for another experiment (Study 2.3). The conditions used were: 100 mg/L of the polymer, 250 mg kaolinite, 5 mg/L starting concentration of phosphate, and 12 hours of continuous shaking in a final volume of 20 mL of water. The result is a baseline for the reduction of phosphate concentration in the aqueous phase when phosphate is the only anion added. Study 2.3 tested the polymers sorption of aqueous phosphate in the presence of other anions at higher concentrations than phosphate. A recipe for anion concentrations in wastewater was used (18). The recipe was modified by changing the concentration of phosphate from 100 mg/L to 5 mg/L phosphate. The concentrations of the other anions for the simulated wastewater were as follows: 190 mg/L $(NH_4)_2SO_4$, 28 mg/L $CaCl_2$, and 180 mg/L $MgSO_4$. The concentration of the polymers was 100 mg/L with 250 mg of kaolinite in 20ml of water. The suspensions were agitated for 12 h. The suspensions were then centrifuged and analyzed by ion chromatography.

The observations made were the change of phosphate concentration in the aqueous phase with the addition of the solid material and polymers. A reduction in phosphate concentration in the aqueous phase was assumed to be caused by sorption of phosphate to the solid material or to the polymer. The control containing only the solid material and phosphate in water was used to estimate the amount of phosphate sorbed to the solid material. The amount of phosphate sorbed by the solid material was then subtracted from the total amount of phosphate removed suspensions containing both suspended solids and polymers resulting in the amount of phosphate sorbed to the

polymers. All results were processed using R Stats software to determine confidence intervals at 95%.

Results and Discussion

In Study 1.1, all the experimental conditions were maintained except the amount of phosphate added was varied from 0.25, 0.5, 1, and 5 mg/L. The amount of phosphate removed from suspension increased as the positive charge density of the polymer increased. The addition of the thiourea group at a density of 40% tripled the amount of phosphate removed from suspension compared to the control polymer C40-00 (Figure 11). Addition of the 2-point and 3-point thiourea at a density of 20%, generally resulted in little or no significant reduction in phosphate removed from suspension compared to the control polymer C40-00 (Figure 11). At the highest concentration of phosphate tested (5 mg/L) the amount of phosphate removed by most of the polymers was approximately zero, suggesting saturation of the available polymer.

In Study 1.2, the phosphate concntration resulting in the highest amount of phosphate removed was used (0.5 mg/L) in addition to adding an equimolar amount of other anions. The polymers generally maintained their sorption of phosphate when several anions at equimolar concentrations to phosphate were added (Figure 12). The reduction in phosphate removed by the polymers containing the thiourea groups was comparable to the work done by Kugimiya (18).

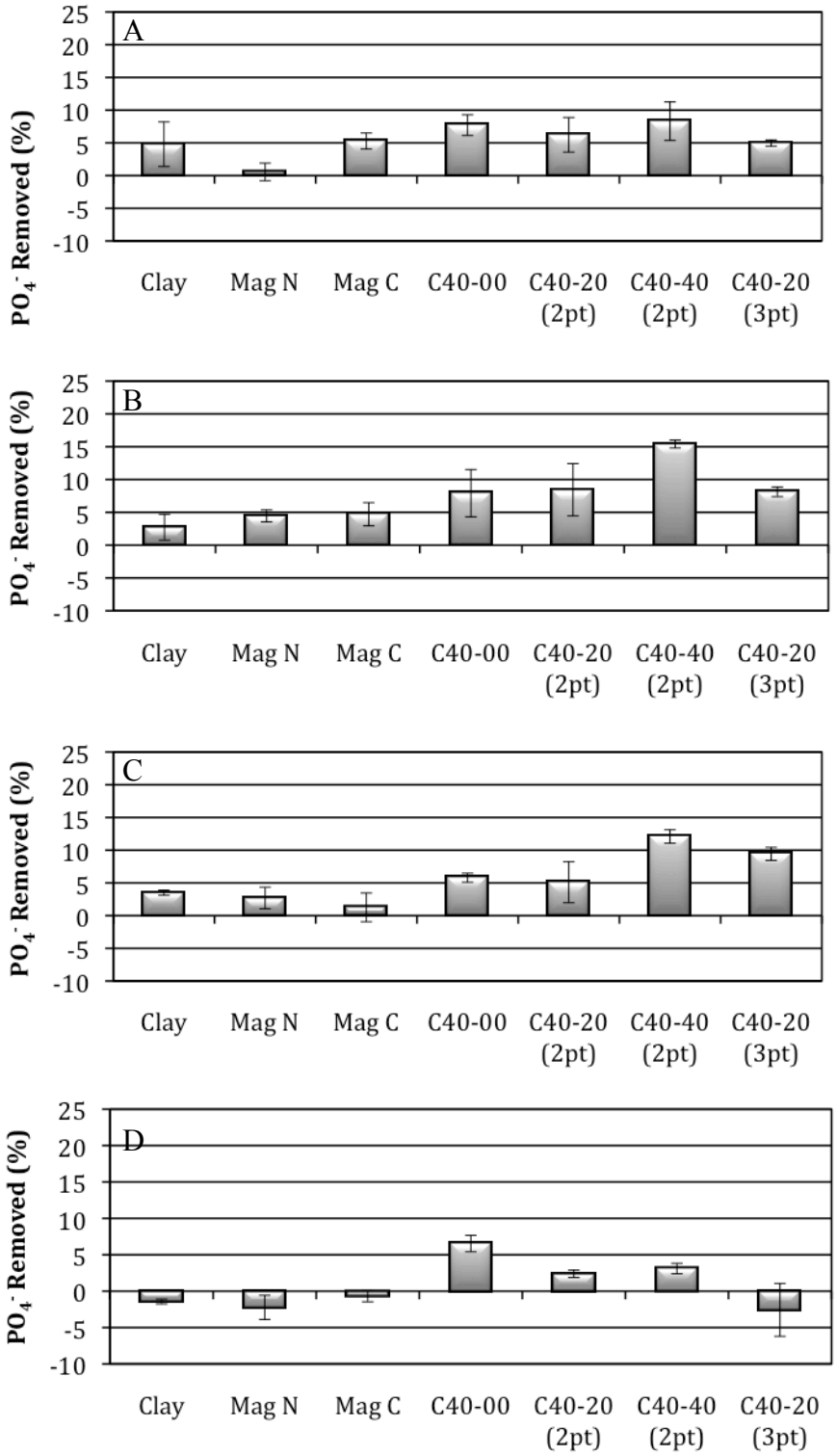

Figure 11. Effect of initial phosphate concentration on polymer sorption of phosphate. (A: 0.25mg/L, B: 0.5 mg/L, C: 1 mg/L, and D: 5 mg/L).

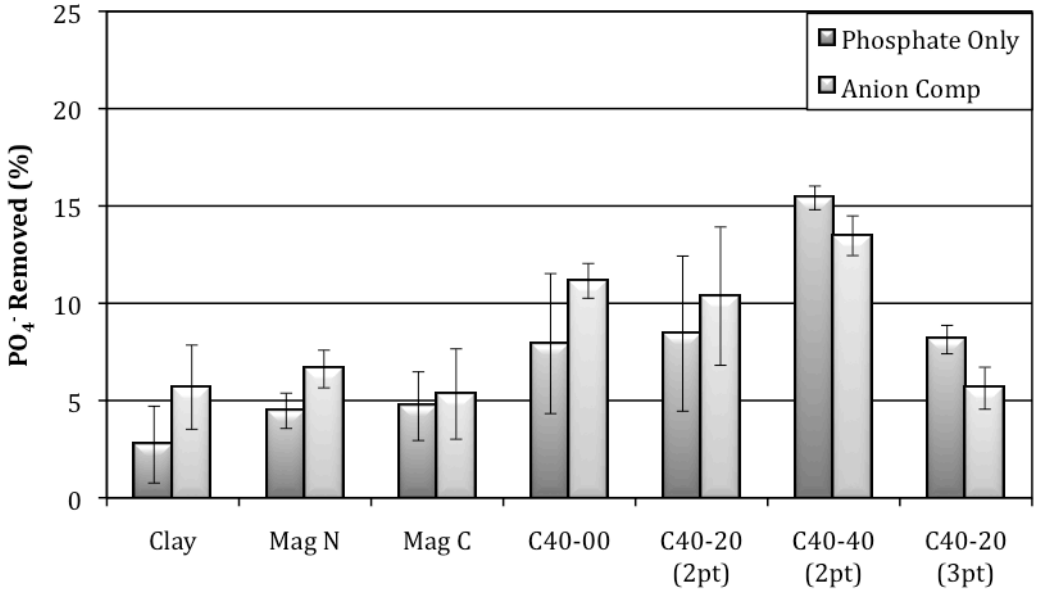

Figure 12. Effect of multi anion competition using equimolar concentrations of NaH_2PO_4, NaF, NaCl, NaBr, $NaNO_2$ and $NaNO_3$, at 8.33 X 10^{-4} (0.5 mg/L) on the sorption of phosphate to the polymers.

In Study 1.3, time was varied from 20 min to 24 h, and the phosphate and other anions were maintained at the same concentration. The amount of phosphate removed from the aqueous phase generally increased up to 12 h then declined at 24 h (Figure 13). The results from Study 1.3 suggested a reversible reaction that required attention to time in Study 2.

In Study 2.1 the polymer concentration was increased from 25 to 100 mg/L, and the amount of time the polymer was allowed to interact was increased from 20 min to 12 h with continuous agitation. Changing these two experimental conditions resulted in an increase in the amount of phosphate removed from suspension by the polymers (Figure 14). The phosphate removed from suspension at a 1mg/L starting concentration of phosphate increased by more than ten-fold for the polymers Magnifloc 494, C40-00 and C40-20(2pt) compared to the same polymers at a polymer concentration of 25 mg/L without agitation for 12 h. The polymers C40-40(2pt) and C40-00(3pt) more than doubled the amount of phosphate removed from suspension.

The previous experiments used a Gonzalez bentonite to represent the suspended sold material. The Gonzalez bentonite is a smetite with a large density of negative charge at its edges. To test the effect of negative charge density of the solid material present on the sorption of phosphate to the polymers bentonite was replaced with kaolnite while maintaining all other experimental conditions (Study 2-2). The effect of adding 500 mg of kaolinite to solutions containing 1 and 5 mg/L phosphate was a decrease in phosphate concentration of 80 and 50% respectively. The sorption of

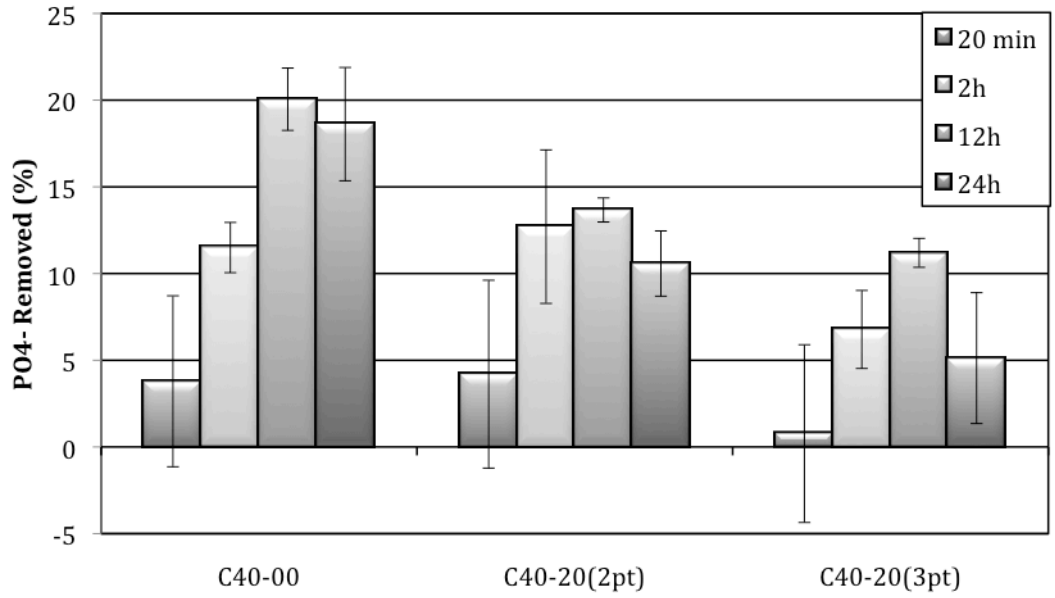

Figure 13. Effect of time on phosphate sorption to the polymers.

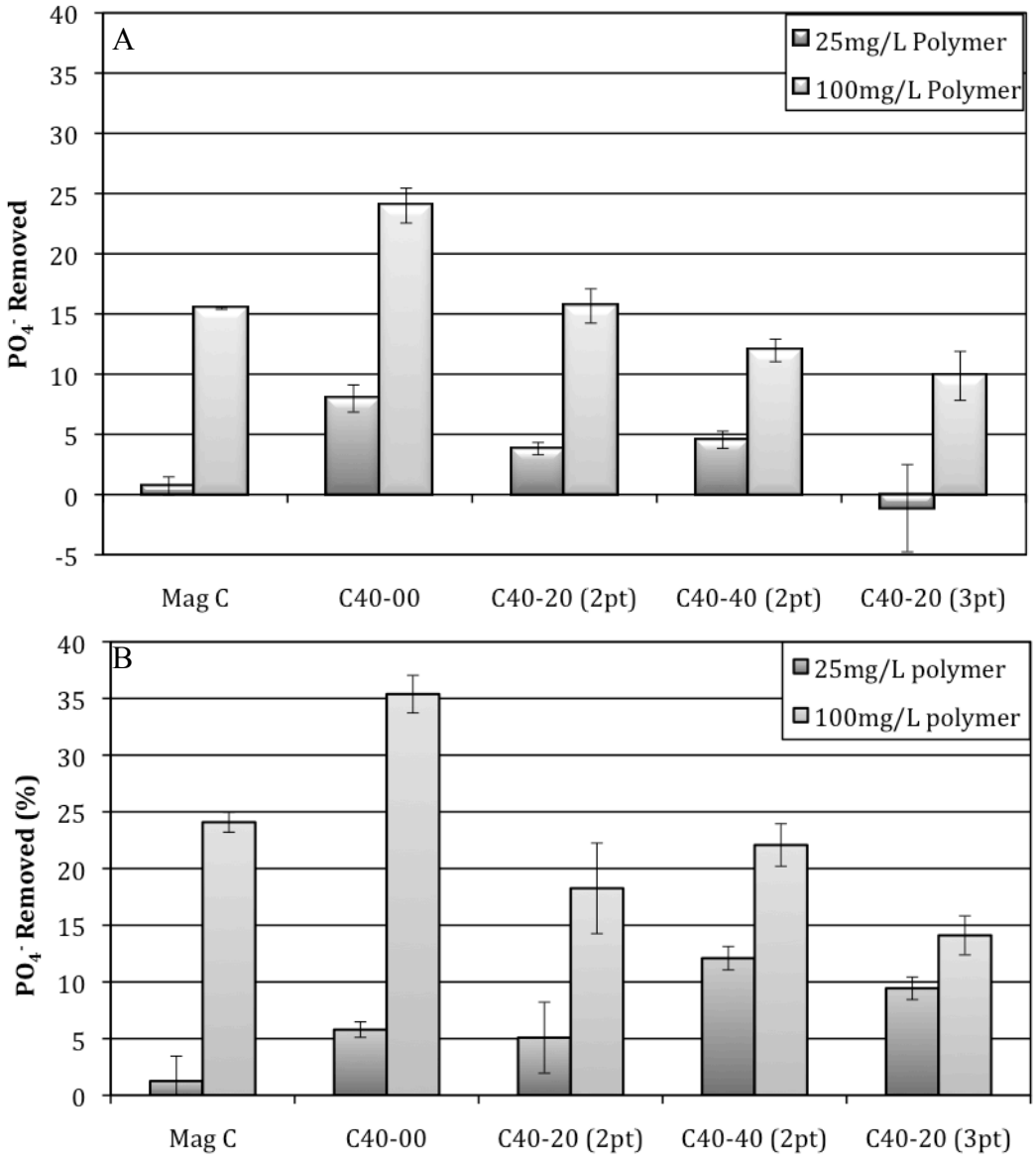

Figure 14. Effect of increased polymer concentration on phosphate sorbed to the polymers. Initial phosphate concentrations were 1 mg/L (A) and 5 mg/L (B).

phosphate to kaolinite reduced the concentration of phosphate in suspension from 1 mg/L to approximately 0.120 mg/L. The reduction in phosphate concentration created conditions where phosphate was too dilute to accurately measure the effect of the polymer treatment. At a 5 mg/L starting phosphate concentration after 12 h, the kaolinite reduced the phosphate concentration in suspension to 2.3 mg/L, leaving enough phosphate in suspension to accurately determine the effect of polymer treatment. The effect of adding kaolinite that substantially decreases the phosphate concentration requires that the aqueous phosphate concentration be recalculated to represent the portion of phosphate left in suspension (Figure 15). The phosphate left in solution was what was left for the polymers to interact with.

Study 2-2 investigated the effect of decreasing the amount of solid material added to solution while maintaining a constant polymer concentration in an attempt to increase the amount of the polymer available to interact with the bulk suspension. Generally, the amount of phosphate removed by C40-00 remained unchanged with decreasing amounts of solid material, suggesting that the amount of positively charged trimethyl ammonium available to interact with the phosphate in solution remained virtually unchanged (Figure 16). The positively charged trimethyl ammonium group interacts strongly with kaolinite at the range of concentrations tested, leaving little available to interact with phosphate in bulk solution. In contrast to C40-00, the addition of C40-40 (2pt), resulted in more phosphate removed from the suspension with

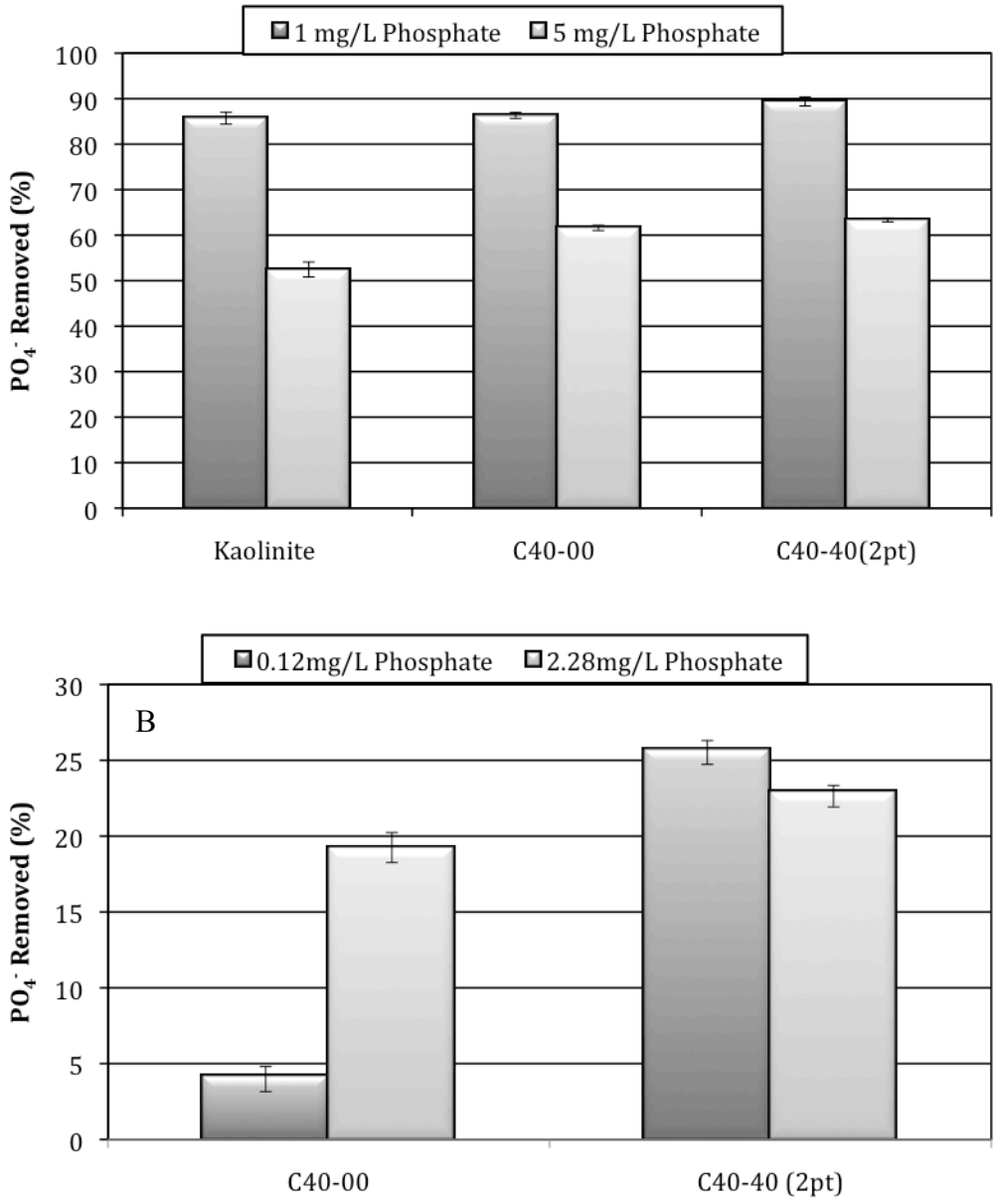

Figure 15. Phosphate removed from solution by polymers using kaolinite to represent the suspended solids (A). Phosphate removed by polymers following partitioning of phosphate by kaolinite (B).

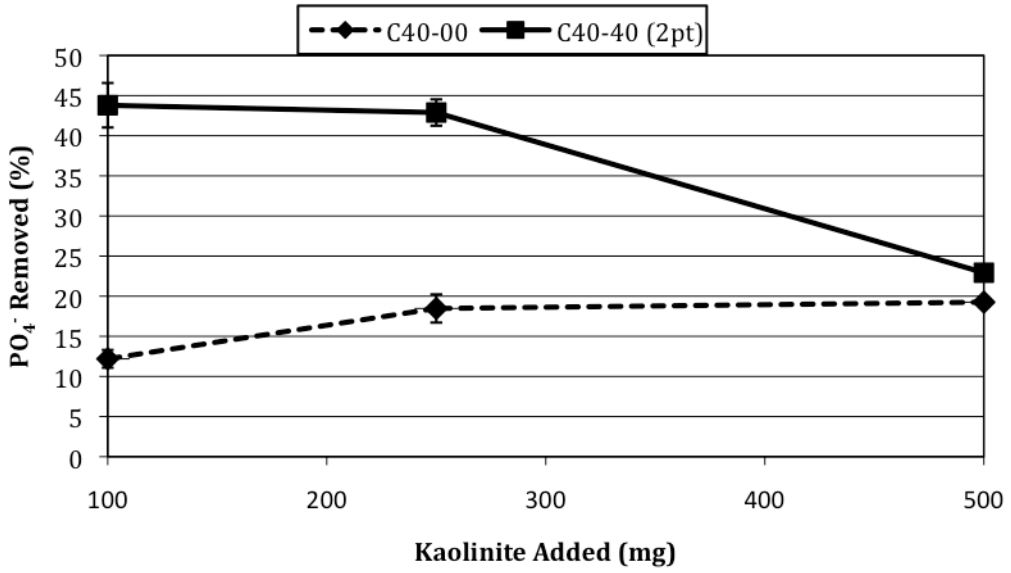

Figure 16. Phosphate removed from solution by polymers with increasing amounts of kaolinite added. (Solution concentration of phosphate: 100 mg 4.0 mg/L, 250 mg – 3.4 mg/L, 500 mg – 2.3 mg/L).

decreasing amounts of kaolinite added. When 250 mg and 100 mg of kaolinite were used, more than twice the amount of phosphate was removed using C40-40 (2pt) compared to C40-00. The polymer C40-40 (2pt), increased phosphate sorption with decreasing kaolinite concentration suggesting that the thiourea has a lower affinity for kaolinite than trimethyl ammonium.

The optimal conditions for phosphate removal from suspension were used in Study 2.3. The goal of Study 2.3 was to test selectivity for phosphate sorption by the polymers in suspensions containing anions at concentrations typical of wastewater. First a baseline sorption test was run for the polymers using 250 mg of kaolinite instead of 500 mg, a 5 mg/L initial phosphate concentration and 100 mg/L final polymer concentration. (Figure 17A). For the selectivity test, anions were added at the following concentrations: 190 mg/L $(NH_4)_2SO_4$, 28 mg/L $CaCl_2$, 180 mg/L $MgSO_4$, and 5 mg/L NaH_2PO_4. The addition of Magnifloc 494C, decreased the amount of phosphate the kaolinite could remove. C40-00, containing only the trimethyl ammonium ion at 40%, did not maintain sorption of phosphate in the presence of higher concentrations of other anions. The lack of selectivity resulted in an overall amount of phosphate removed similar to that of Magnifloc 494C. While the higher charge density on C40-00 results in more positively charged groups available to interact with phosphate in bulk solution, the available quaternary ammonium group was not selective for phosphate. In conditions with competitive anions at higher concentrations than phosphate, no phosphate was removed by either C40-20(2pt) or C40-40(2pt) (Figure 17).

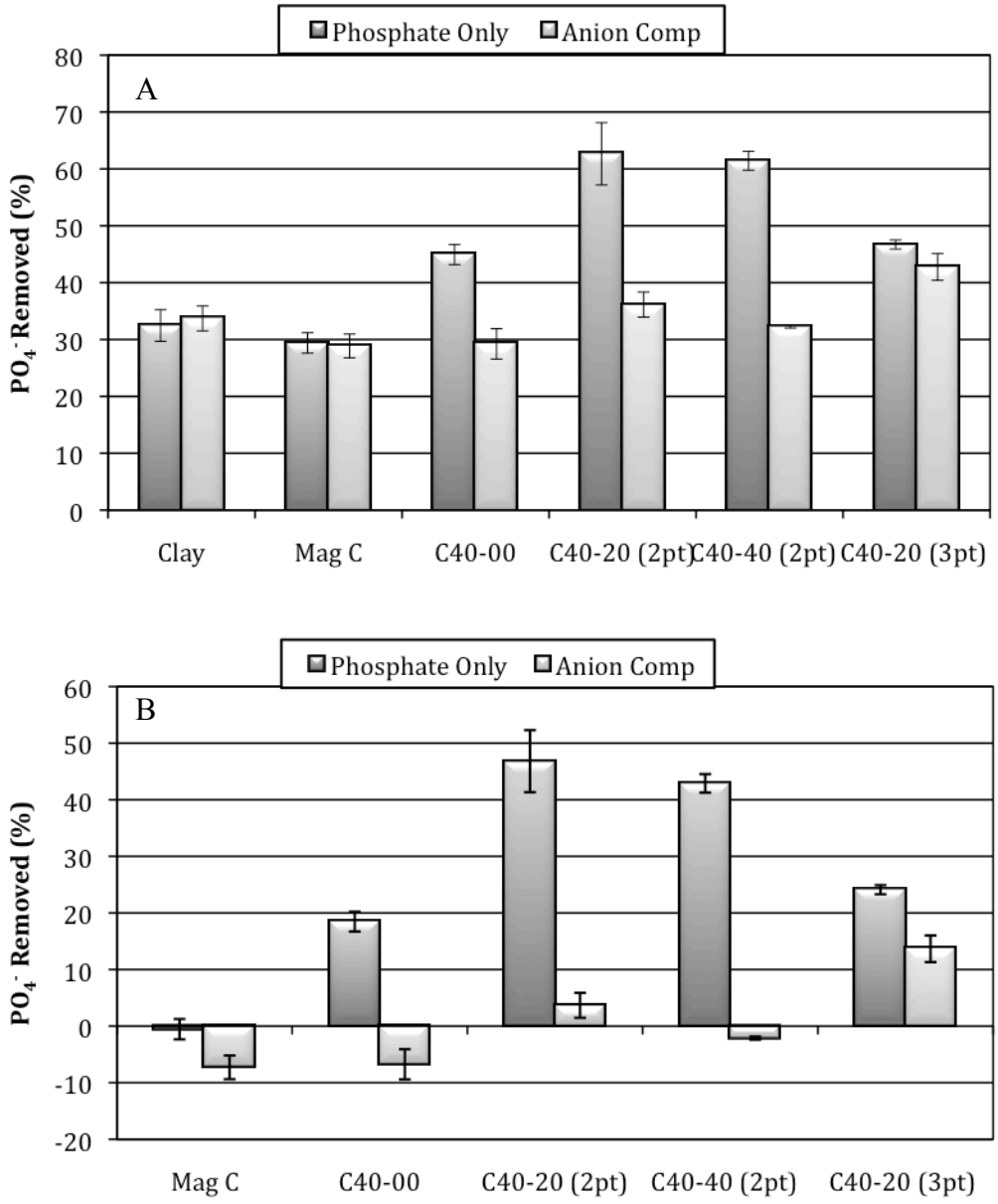

Figure 17. Phosphate removed by polymers with an initial phosphate concentration of 5 mg/L and other anions at concentrations similar to wastewater (A), and the same results with the phosphate removed by kaolinite partitioned to examine the portion removed by the polymers.

While the addition of a thiourea group that can hydrogen bond to phosphate at two points would increase the sorption of phosphate to the polymer, the two point interaction was not enough to allow selectivity for phosphate in the presence of other anions at higher concentrations. The polymer C40-20 (3pt) using a three-point binding with phosphate, removed 13% of the phosphate from suspension in the presence of other anions compared to 24% without competing anions. A three-point hydrogen bonding interaction with phosphate was needed to gain some selectivity for phosphate in the presence of other anions at higher concentrations than phosphate (21).

The two studies presented here suggest that it is possible to modify polymer flocculants to increase their sorption of phosphate. While a 2point hydrogen bonding interaction was shown to remove phosphate from water it had no affinity for phosphate in the presence of anions at higher concentrations than phosphate. To remove phosphate from a suspension similar to wastewater, a thiourea with 3 points of hydrogen bonding or more would be required as suggested in published work (22).

CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

The experiments described in the previous chapters demonstrate that it is possible to modify polymer flocculants to increase the sorption of contaminants from suspension. The polymer flocculants modified by the addition of a trapping group reduced the concentration of the respective contaminant in the aqueous phase. The addition of the trapping groups to the polymer flocculants did not interfere with the formation of flocs.

When the cyclic secondary amine was added to the polymer flocculant, the resulting decrease in atrazine concentration in suspension suggests that atrazine was bound to the polymer. The amount of atrazine removed from suspension was maintained up to 24 h. The continued removal of atrazine from suspension suggested that there was no competition for the cyclic secondary amine by other compounds. In a situation where the polymer might be applied to a runoff pond, the aqueous layer would not need to be removed immediately but could be removed up to or possibly longer than 24 h after application of the polymer.

When the two thiourea-trapping groups designed for phosphate removal were used, more phosphate was removed from solution when compared to the control polymers Magnifloc 494C and 700N. The addition of the 2-point thiourea group to the polymer at 40% density removed significantly more phosphate from the aqueous phase compared to the other polymers tested. The time dependence of the sorption of phosphate to the modified polymer flocculants suggests competition for the thiourea

binding site by the other anions. The thiourea molecule with a three-point interaction with phosphate maintained some selectivity for phosphate when in the presence of other anions at concentrations simulating conditions found in wastewater.

Conclusions

The effect of adding a trapping group to the polymer consistently resulted in an improvement in sorption of the contaminant to the polymer when compared to commercially available flocculants. While the results from the overall study suggest that it is possible to modify polymer flocculants to remove contaminants from suspension, when put in context of a practical application, the concentration of the polymer added was high. In the case of atrazine as a test contaminant, the polymers were added at a concentration of 1 mg/mL, meaning that to treat 1 m^3 of water a kg of the polymer must be added. In the case of phosphate as a test contaminant, the application rate was 100 mg/L or 100 g of polymer per m^3 of water. The EPA currently limits the application rate of polyacrylamides to 1 mg/L. The polymers in this study require application at concentrations much higher than that EPA limit. The EPA limit on application of flocculants is only for polyacrylamides. Other polymer backbones could be used such as IDC and PDADMAC and would likely give similar results to those presented here without the EPA guidelines.

Polymer flocculants are designed to interact strongly with suspended solids. The trimethyl ammonium group has a permanent positive charge that interacts strongly with negatively charged solids such as clays. The acrylamide group, while nonionic, has a high relative polarity due to the amide group, allowing acrylamide to interact with either

negatively or positively charged solid material. The modified polymers presented here predominantly contained the trimethyl ammonium monomer and the acrylamide monomer. The modified polymer C40-40 (2pt) containing the thiourea-trapping group at density of 40% had the highest density of all the trapping groups tested but still had 60% of the monomer makeup designed to interact with the suspended solids. The polymer makeup containing a majority of the trimethyl ammonium and acrylamide monomers resulted in a polymer that interacted strongly with the suspended solids. The strong interaction of the polymer with the suspended solids likely leaves little of the trapping group available to interact with contaminants in the aqueous phase.

The trapping group left to interact with contaminants in the aqueous phase after the flocs have formed and settled would most likely be the section of the polymer bridging between two or more particles within a floc. The segments of the polymer in the bridge are the remnants of loops and tails that extended away from one of the particles prior to interacting with the next particle to form the floc. To increase the amount of the trapping group available to interact with contaminants in the aqueous phase the amount and the size of bridges formed by the polymers would likely need to be increased. To extend more of the polymer into solution in a bridge, the polymer must not interact with the suspended solids. To decrease the sorption of a polymer flocculant to suspended solids, monomers that do not interact or interact poorly with suspended solids must be used. Most or all of the trimethyl ammonium and acrylamide monomers must be removed and replaced with monomers that do not interact with suspended solids. Replacing acrylamide and trimethyl ammonium monomers with monomers from

other types of polymer flocculants, such as ICD or PDADMAC, would likely give similar results to those presented here. ICD and PDADMAC are designed to interact strongly with suspended solids so the resulting modified polymer based on IDC and PDADMAC would likely result in a modified polymer flocculant where little of the trapping group was available.

The interaction of a polymer flocculant with different minerals present in aqueous suspension would affect the amount and size of bridges formed by the polymer flocculant. The interaction of the polymer with other minerals present in the environment, such as illite and vermiculite, would likely influence the effectiveness of the polymer to sorb contaminants from solution. Suspended solids found in the environment are not limited to minerals and could include material such as organic matter, microbial cells, etc.

The type of suspended material present in a water body is only one of many environmental factors that may affect the efficiency of the polymer to sorb contaminants from suspension. Other conditions found in the environment would affect the interaction of the trapping group with the contaminant. Environmental variables such as pH, temperature and redox conditions would likely affect the interaction of the trapping group with the respective contaminant. An additional variable affecting the polymers use *in situ* would be microbial activity. Microbes may degrade the polymer with the sorbed contaminant *in situ*. The trapping groups used in this study are all linked to the polymer through an amide bond. Enzymes secreted from microbes might hydrolyze the amide bond resulting in an acid on the polymer and an amine on the trapping group. The

trapping group would then be free of the polymer and could diffuse back into solution with the contaminant.

A polymer flocculant that would be more effective at sorbing contaminants from solution requires a polymer backbone that does not interact strongly with the suspended solids. A polymer that does not interact strongly with suspended solids will likely not function as a flocculant. An example of a polymer that might not interact with suspended solids is polyethylene glycol (PEG). While PEG has enough polarity to be water soluble, it is less polar than acrylamide. Addition of a trapping group to PEG should increase the amount of trapping group available to interact with contaminants in the aqueous phase. The modified PEG polymer might also lead to a polymer that cannot aggregate the suspended solids into flocs. Adding the trimethyl ammonium monomer back onto the polymer at low densities (<5%) might allow the polymer to interact with the suspended solids but only where the trimethyl ammonium group is present on the polymer. The development of new polymers such as a modified PEG polymer could result in a polymer flocculant that forms large loops and tails. The large loops and tails would position the trapping group away from the surface of the suspended solids allowing the trapping group to interact with the contaminants in the aqueous phase.

An alternative to the development of a polymer flocculant with large loops and tails would be to use a two polymer flocculation system. In a two polymer system, the first polymer added to solution would not interact with the suspended solids, such as the modified PEG described above. The first polymer would be free in solution and be more likely to interact with the contaminants in solution. The second polymer added would be

a polymer flocculant that would remove both the first polymer added and the suspended solids. The two polymer system would reduce the concentration of contaminants in solution by removing both the contaminants sorbed to the suspended solids and the contaminants sorbed to the first polymer. Other material may be better suited for sorption of particular contaminants than a modified polymer (i.e., activated carbon for atrazine or kaolinite for phosphate). In the absence of alternative material to sorb a particular contaminant, a modified polymer could likely be made.

For the studies presented here, individual molecules were chosen that interact with a single contaminant. Combining some of the principle components required by the molecules to interact with the contaminants, new trapping groups could be developed that would interact with multiple test contaminants. The new trapping groups could then be added to polymers creating new modified polymers that would target multiple contaminants simultaneously and remove the contaminants from solution as flocculant or as part of the two polymer system.

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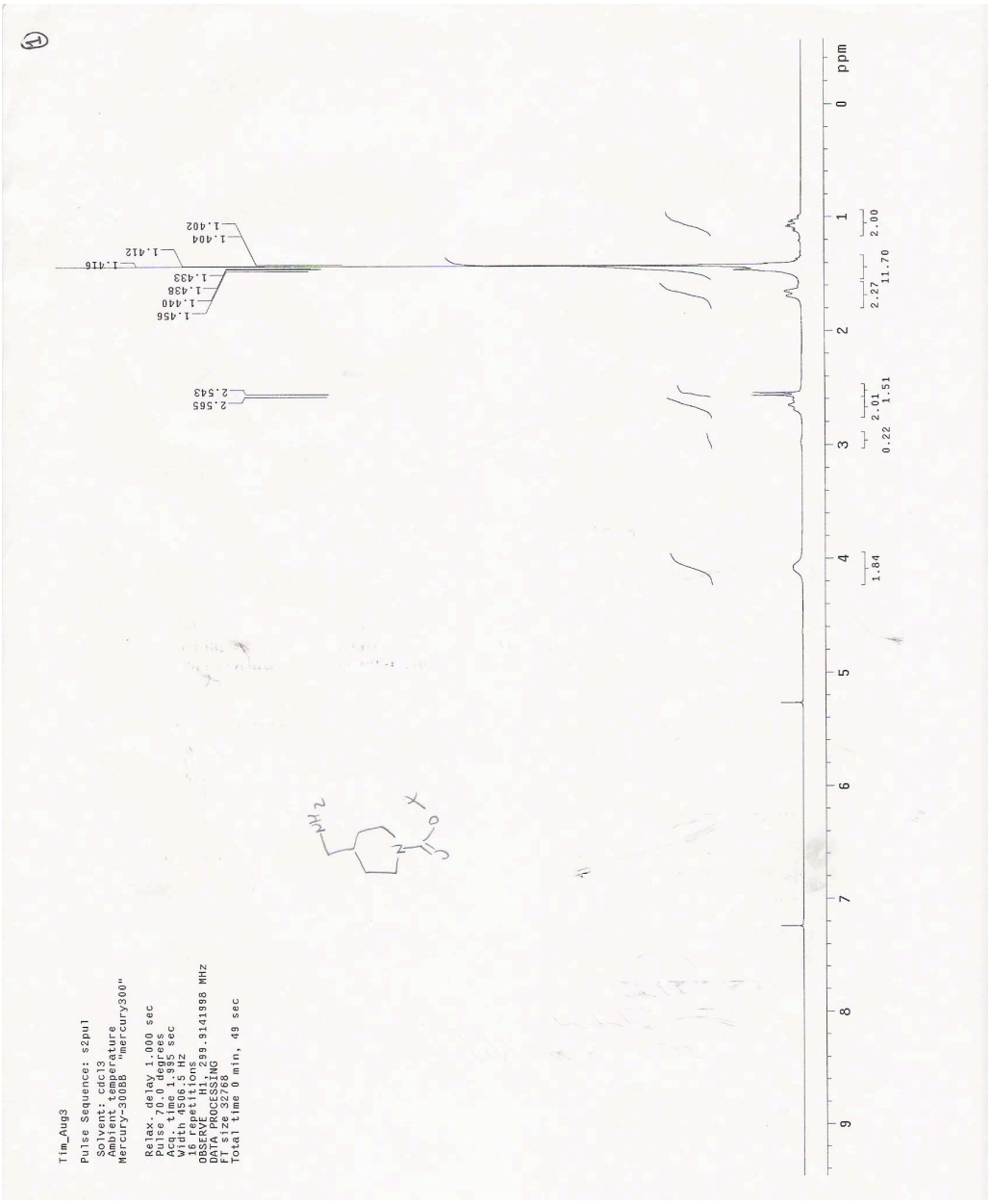
APPENDIX A

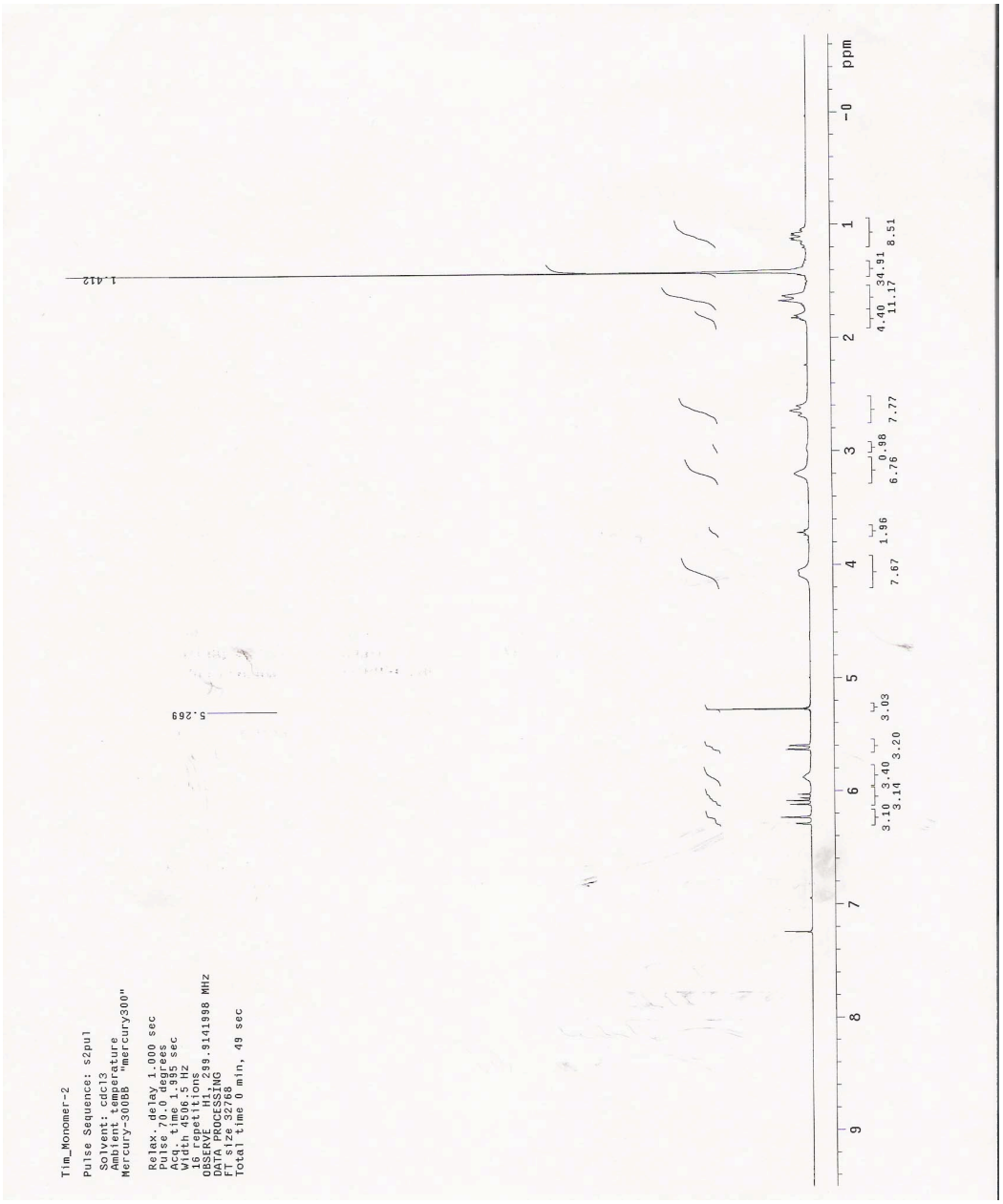
EXPERIMENTAL DATA AND ANOVA ANALYSIS FOR CHAPTER II

ANOVA analysis was accomplished using R Stats: R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

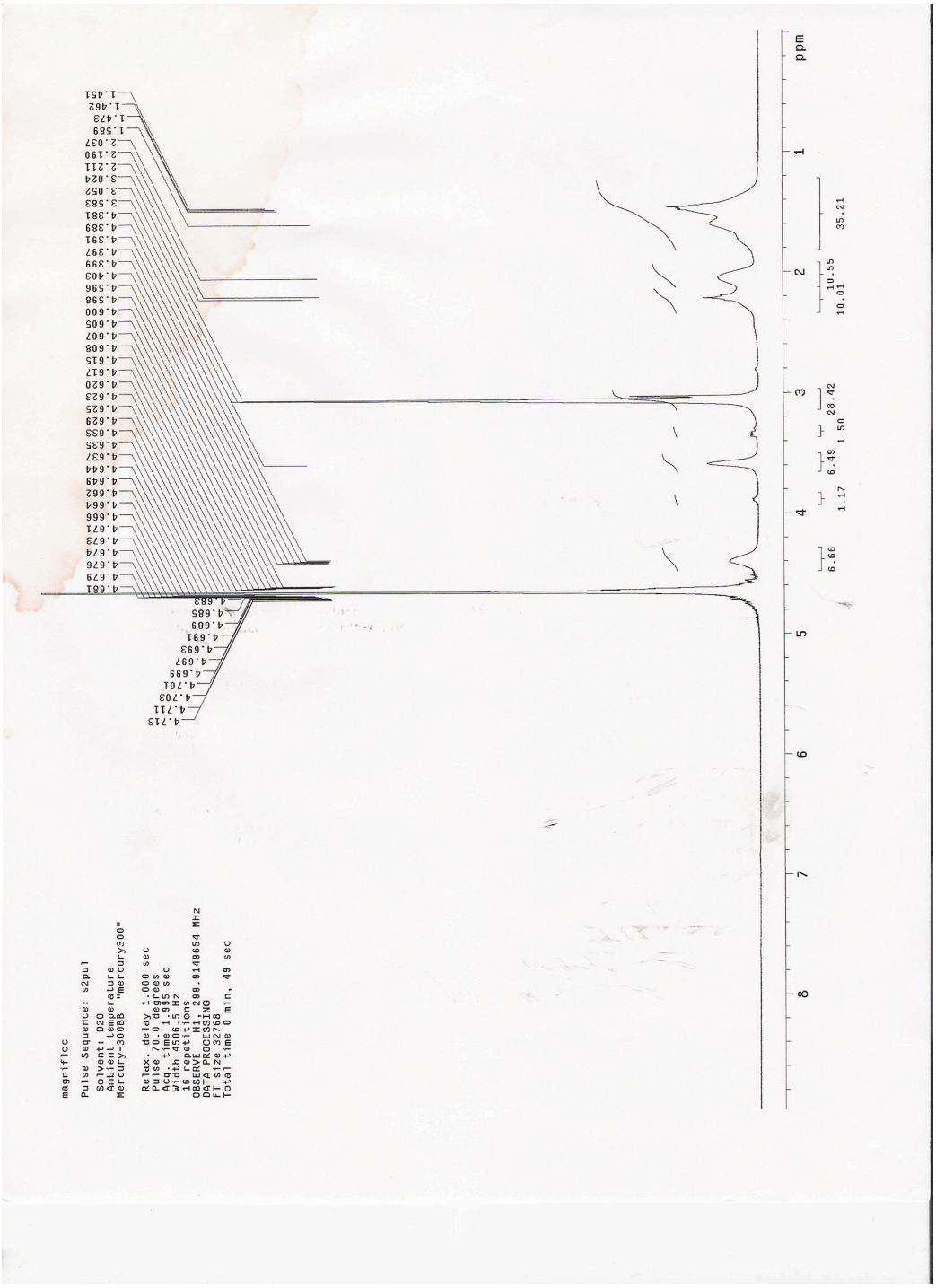
A1. NMR of 4-aminomethyl-piperidine-1-carboxylic acid tert-butyl ester



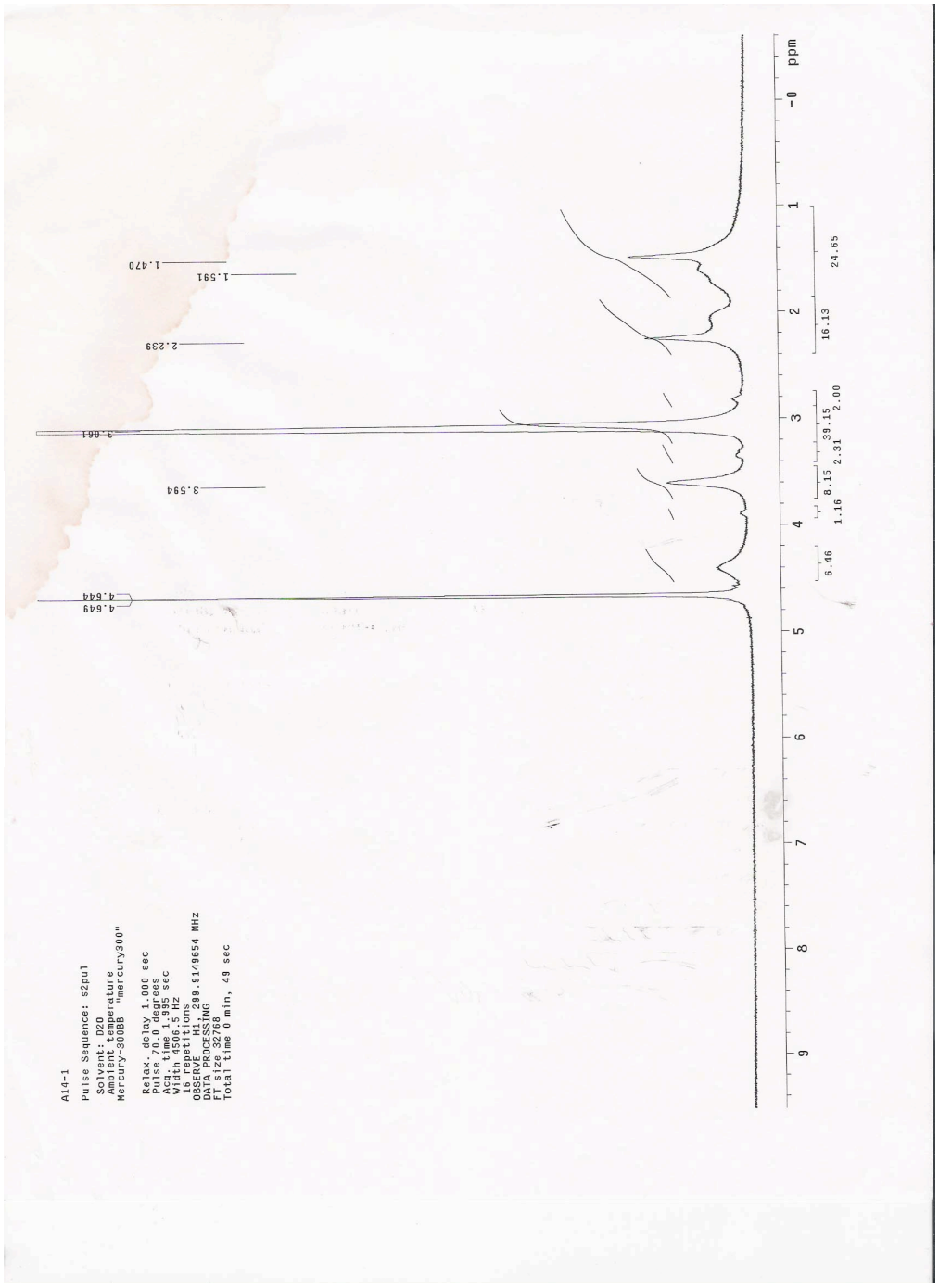
A2. NMR of 4-(acryloylamino-methyl)-piperidine-a-carboxylic acid tert-butyl ester



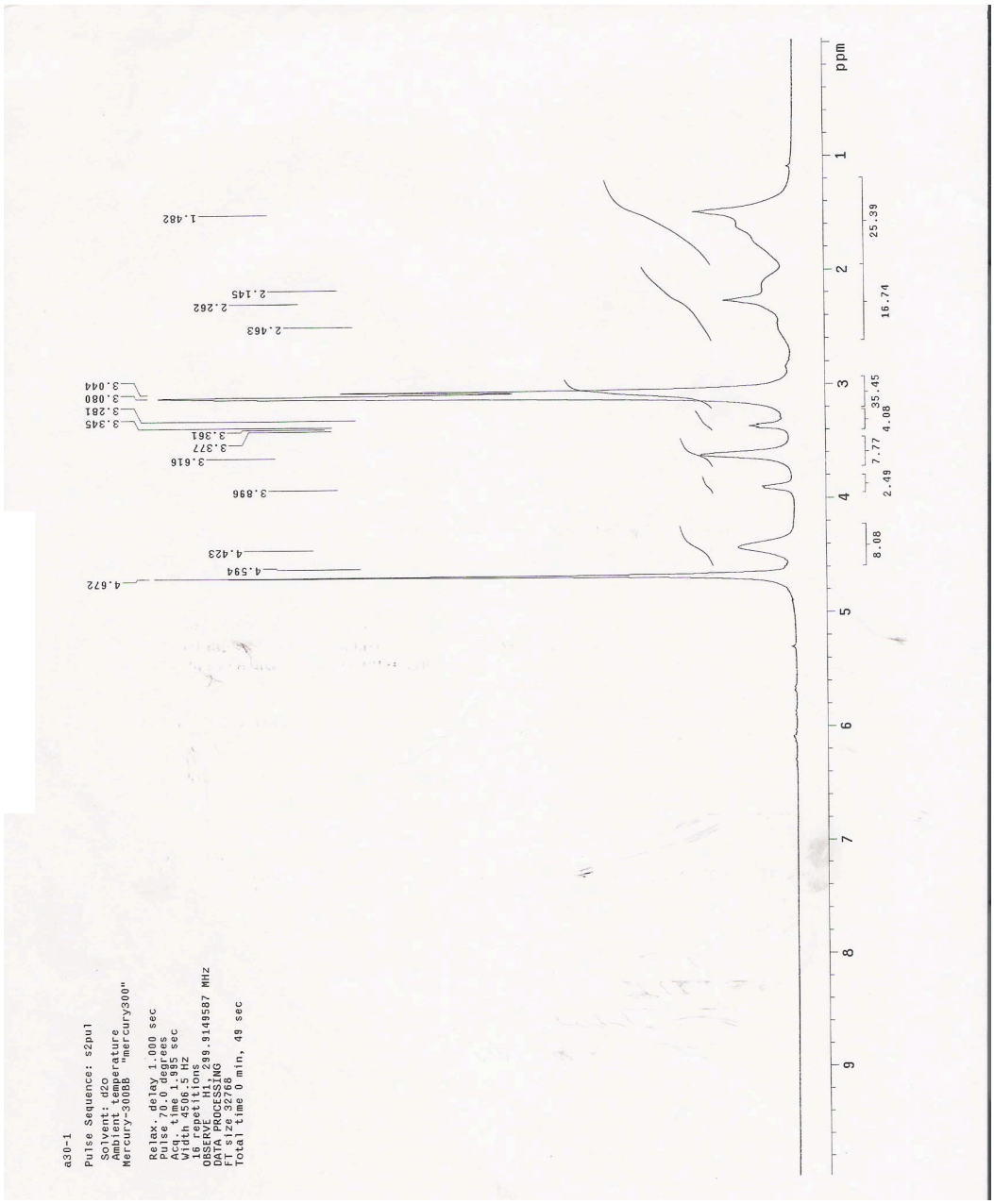
A3. NMR of Magnifloc 494C



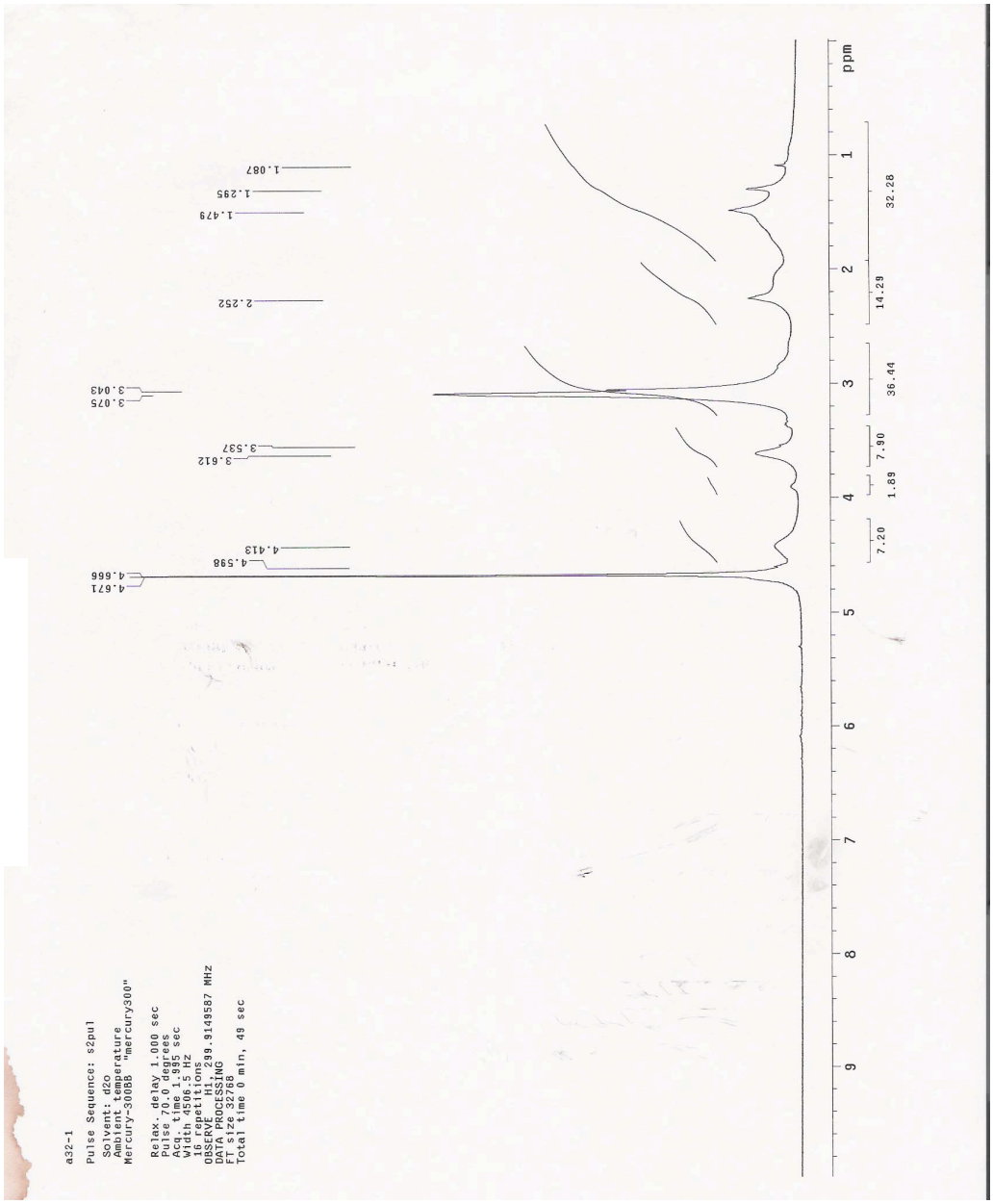
A4. NMR of C40-00



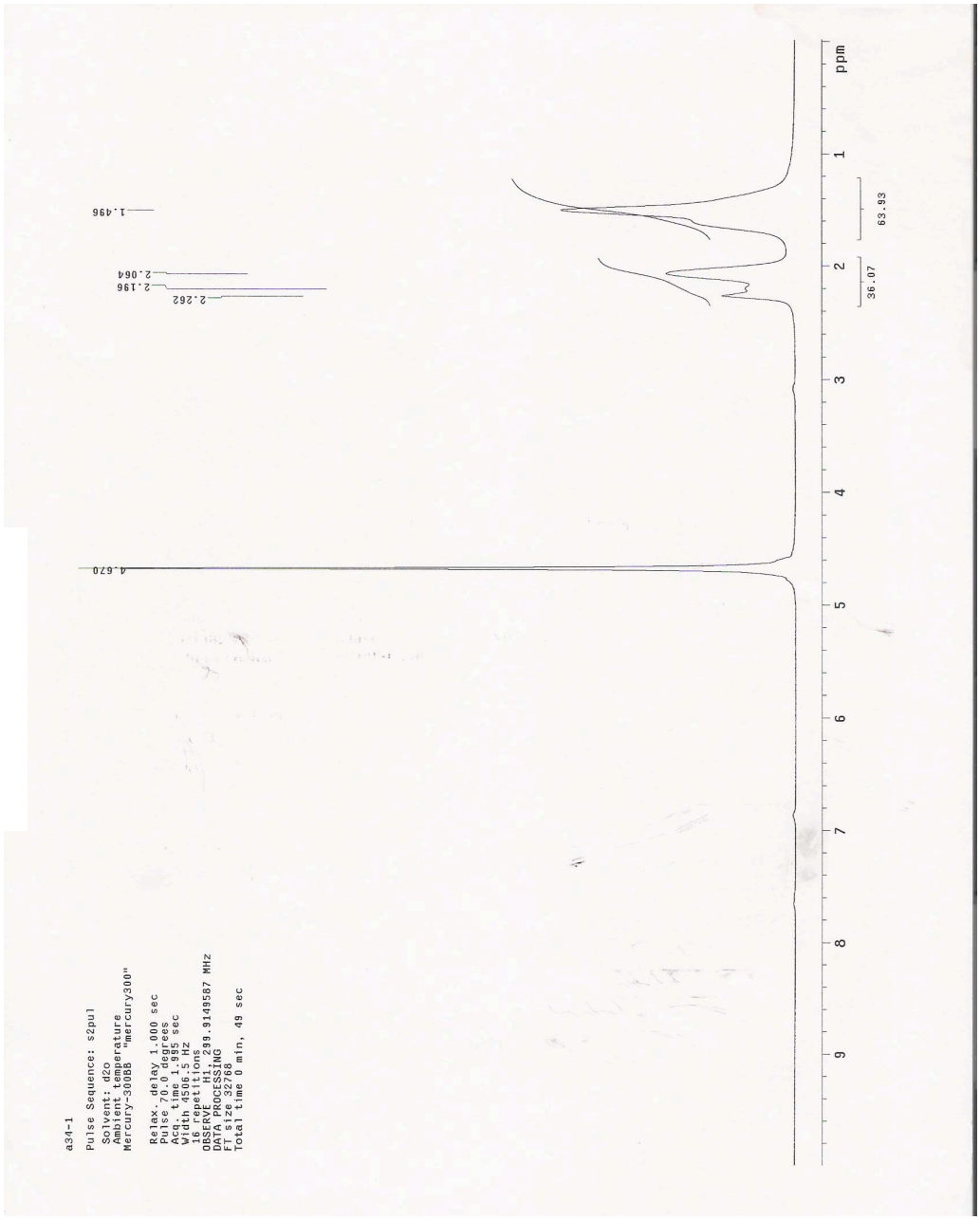
A5. NMR of C40-0.4



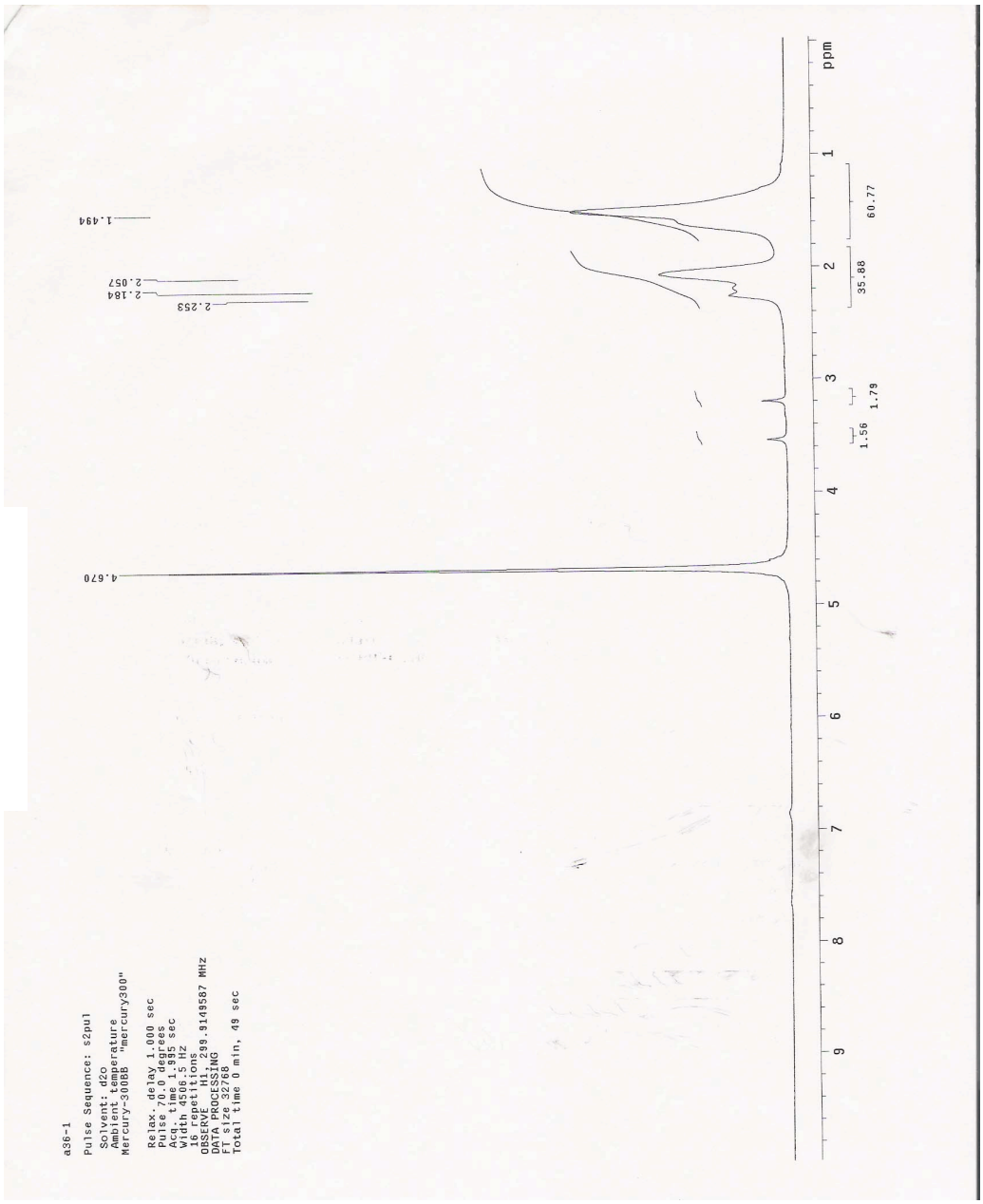
A6. NMR of C40-04



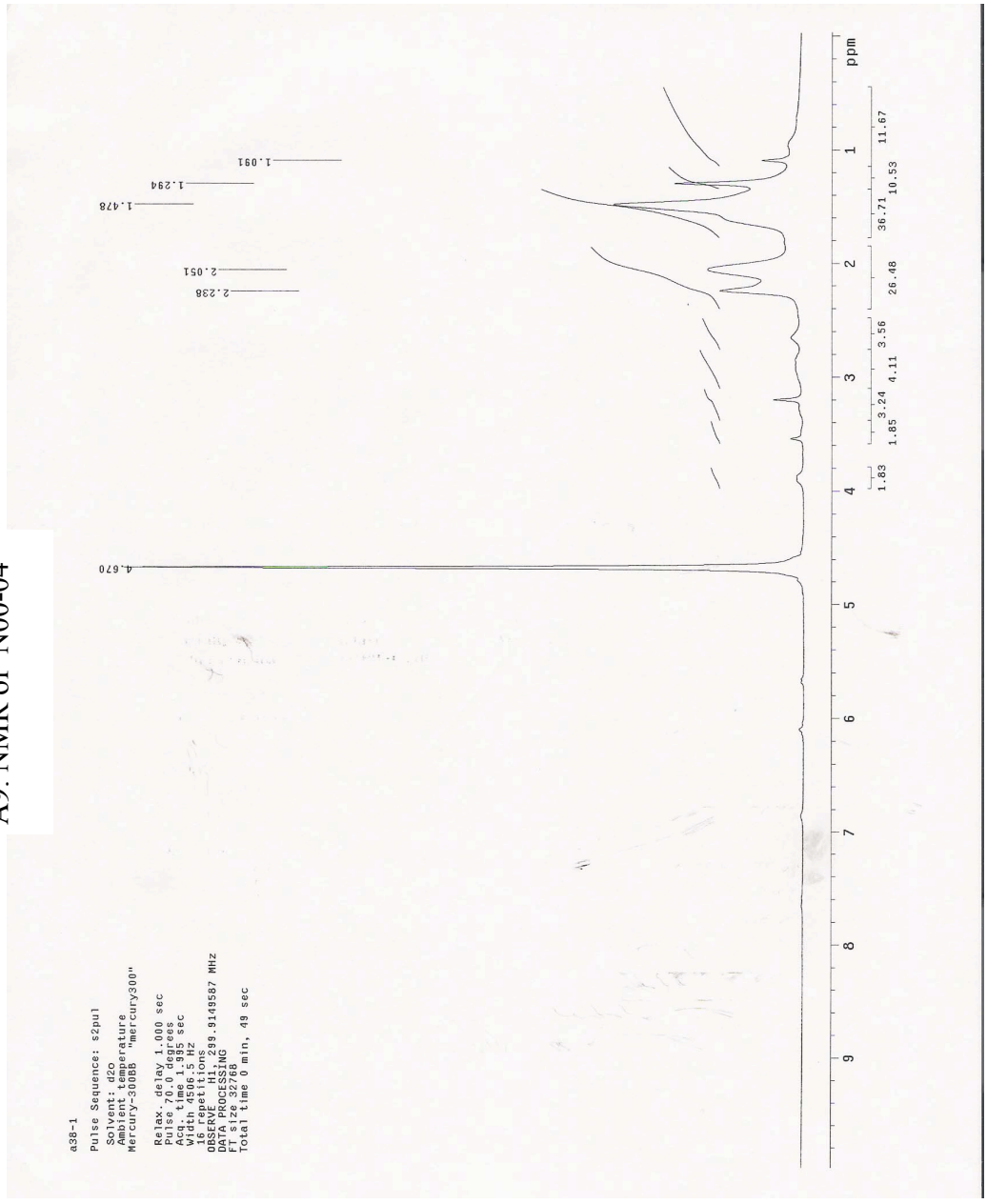
A7. NMR of N00-00



A8. NMR of N00-0.4



A9. NMR of N00-04



A10. Experimental Data for Figure 6

Sample	Desc	DPM	avg/smpl	avg/rep	conc/ml	stddev	error/ml	conc/5ml	AT rem	error/5ml	% rem	%error
1.1	Blank	949.39										
1.2	Blank	978.92										
2.1	Blank	1093										
2.2	Blank	1050.4	1071.685									
3.1	Blank	1083.1										
3.2	Blank	1091.7	1087.36	1079.5	0.4	11.084	0.0041	2		0.020535		
4.1	Blank (clay)	992										
4.2	Blank (clay)	1033.8	1012.89									
5.1	Blank (clay)	1053										
5.2	Blank (clay)	1078.3	1065.63									
6.1	Blank (clay)	1006.3										
6.2	Blank (clay)	1023.1	1014.73	1031.1	0.38205	29.932	0.0111	1.91026	0.0897	0.055455	4.487	2.7727
7.1	Mag C	905.64										
7.2	Mag C	957.84	931.74									
8.1	Mag C	945.24										
8.2	Mag C	867.64	906.44									
9.1	Mag C	919.94										
9.2	Mag C	861.2	890.57	909.58	0.33703	20.764	0.0077	1.68516	0.3148	0.038469	15.74	1.9235
10.1	Mag N	1019.6										
10.2	Mag N	1035	1027.305									
11.1	Mag N	987.78										
11.2	Mag N	1032.5	1010.14									
12.1	Mag N	1062.5										
12.2	Mag N	1059.5		1018.7	0.37747	12.137	0.0045	1.88736	0.1126	0.022487	5.632	1.1243

13.1 C40-00	26.28										
13.2 C40-00	32.14	29.21									
14.1 C40-00	504.88										
14.2 C40-00	655.57	580.225									
15.1 C40-00	699.4										
15.2 C40-00	888.42	793.91	687.07	0.25458	151.1	0.056	1.27291	0.7271	0.279935	36.35	13.997
16.1 C40-0.4	496.81										
16.2 C40-0.4	534.22	515.515									
17.1 C40-0.4	463.98										
17.2 C40-0.4	468.97	466.475									
18.1 C40-0.4	596.26										
18.2 C40-0.4	589.8	593.03	525.01	0.19453	63.809	0.0236	0.97266	1.0273	0.118217	51.37	5.9109
19.1 C40-04	436.79										
19.2 C40-04	431.09	433.94									
20.1 C40-04	407.01										
20.1 C40-04	417.26	412.135									
21.1 C40-04	410.07										
21.2 C40-04	409.9	409.985	418.69	0.15514	13.253	0.0049	0.77569	1.2243	0.024554	61.22	1.2277
22.1 N00-00	1087.3										
22.2 N00-00	1067.5	1077.375									
23.1 N00-00	1108.4										
23.2 N00-00	1118.3	1113.325									
24.1 N00-00	1109.5										
24.2 N00-00	1081.6	1095.58	1095.4	0.40589	17.975	0.0067	2.02947	-0.0295	0.033303	-1.473	1.6651

25.1	N00-0.4	844.72										
25.2	N00-0.4	864.52	854.62									
26.1	N00-0.4	884.46										
26.2	N00-0.4	889.95	887.205									
27.1	N00-0.4	862.9										
27.2	N00-0.4	868.74	865.82	869.22	0.32207	16.556	0.0061	1.61037	0.3896	0.030672	19.48	1.5336
28.1	N00-04	649.71										
28.2	N00-04	642.42	646.065									
29.1	N00-04	688.95										
29.2	N00-04	712.69	700.82									
31.1	N00-04	650.72										
30.2	N00-04	664.78	657.75	668.21	0.2476	28.838	0.0107	1.23798	0.762	0.053427	38.1	2.6713

A10. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

test	diff	lwr	upr	p adj
C40-0.4-C40-04	106.32	8.3415	204.2985	0.0245
N00-04-C40-04	249.525	151.55	347.5035	0
C40-00-C40-04	268.38083	158.84	377.9242	0
N00-0.4-C40-04	450.52833	352.55	548.5069	0
MagC-C40-04	490.89667	392.92	588.8752	0
Blank(clay)-C40-04	612.39667	514.42	710.3752	0
MagN-C40-04	614.13833	516.16	712.1169	0
N00-00-C40-04	676.74	578.76	774.7185	0
N00-04-C40-0.4	143.205	45.226	241.1835	0.0007
C40-00-C40-0.4	162.06083	52.518	271.6042	0.0006
N00-0.4-C40-0.4	344.20833	246.23	442.1869	0
MagC-C40-0.4	384.57667	286.6	482.5552	0
Blank(clay)-C40-0.4	506.07667	408.1	604.0552	0
MagN-C40-0.4	507.81833	409.84	605.7969	0
N00-00-C40-0.4	570.42	472.44	668.3985	0
C40-00-N00-04	18.855833	-90.687	128.3992	0.9997
N00-0.4-N00-04	201.00333	103.02	298.9819	1E-06
MagC-N00-04	241.37167	143.39	339.3502	0
Blank(clay)-N00-04	362.87167	264.89	460.8502	0
MagN-N00-04	364.61333	266.63	462.5919	0
N00-00-N00-04	427.215	329.24	525.1935	0
N00-0.4-C40-00	182.1475	72.604	291.6908	8E-05
MagC-C40-00	222.51583	112.97	332.0592	2E-06
Blank(clay)-C40-00	344.01583	234.47	453.5592	0
MagN-C40-00	345.7575	236.21	455.3008	0
N00-00-C40-00	408.35917	298.82	517.9025	0
MagC-N00-0.4	40.368333	-57.61	138.3469	0.9115
Blank(clay)-N00-0.4	161.86833	63.89	259.8469	9E-05
MagN-N00-0.4	163.61	65.631	261.5885	7E-05
N00-00-N00-0.4	226.21167	128.23	324.1902	1E-07
Blank(clay)-MagC	121.5	23.521	219.4785	0.006
MagN-MagC	123.24167	25.263	221.2202	0.005
N00-00-MagC	185.84333	87.865	283.8219	7E-06
MagN-Blank(clay)	1.741667	-96.237	99.7202	1
N00-00-Blank(clay)	64.343333	-33.635	162.3219	0.4588
N00-00-MagN	62.601667	-35.377	160.5802	0.4958

	Blank (clay)	Mag C	Mag N	C40-00	C40-0.4	C40-04	N00-00	N00-0.4	N00-04
Blank (clay)		N.S.	N.S.	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05
Mag C	N.S.		N.S.	<0.05	<0.05	<0.05	<0.05	N.S.	<0.05
Mag N	N.S.	N.S.		<0.05	<0.05	<0.05	N.S.	<0.05	<0.05
C40-00	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	N.S.
C40-0.4	<0.05	<0.05	<0.05	<0.05		N.S.	<0.05	<0.05	<0.05
C40-04	<0.05	<0.05	<0.05	<0.05	N.S.		<0.05	<0.05	<0.05
N00-00	N.S.	<0.05	N.S.	<0.05	<0.05	<0.05		<0.05	<0.05
N00-0.4	<0.05	N.S.	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05
N00-04	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05	<0.05	<0.05	

Confidence Interval

	%removed	Stddev	conint t
Blank (clay)	4.487091901	2.7727	4.66982
Mag C	15.74206806	1.9235	3.2419
C40-00	36.35449933	13.997	23.5851
C40-0.4	51.36676941	5.9109	9.9634
C40-04	61.2155683	1.2277	2.06854
Mag N	5.632119757	1.1243	1.8949
N00-00	-1.4732594	1.6651	2.79852
N00-0.4	19.48153003	1.5336	2.58442
N00-04	38.10118208	2.6713	4.50123

A11. Experimental Data for Figure 7

Sample	Desc	DPM	avg/smpl	avg/rep	conc/ml	stddev	error/ml	conc/5ml	AT rem	error/5ml	% rem	%error
1.1	Blank	1931										
1.2	Blank	1929	1930									
2.1	Blank	1787										
2.2	Blank	1770	1778.5									
3.1	Blank	1772										
3.2	Blank	1751	1761.5	1823.3	4	92.766	0.2035	20		1.017546		
4.1	Blank(clay)	1775.5										
4.2	Blank(clay)	1855.7	1815.59									
5.1	Blank(clay)	1839.4										
5.2	Blank(clay)	1824.1	1831.75									
6.1	Blank(clay)	1832.2										
6.2	Blank(clay)	1810.4	1821.32	1822.9	3.99901	8.1909	0.018	19.9951	0.0049	0.089845	0.0247	0.4492
7.1	MagC	1749.7										
7.2	MagC	1749.7	1749.68									
8.1	MagC	1805.6										
8.2	MagC	1848	1826.81									
9.1	MagC	1747.2										
9.2	MagC	1792.3	1769.72	1782.1	3.90948	40.021	0.0878	19.5474	0.4526	0.438983	2.2631	2.1949
10.1	C40-00	1517.3										
10.2	C40-00	1498.7	1507.99									
11.1	C40-00	1451.1										
11.2	C40-00	1555.4	1503.26									
12.1	C40-00	1547.3										
12.2	C40-00	1595.1	1571.22	1527.5	3.35098	37.943	0.0832	16.7549	3.2451	0.416199	16.226	2.081

13.1	C40-0.4	1329.4										
13.2	C40-0.4	1354.5	1341.94									
14.1	C40-0.4	1170.5										
14.2	C40-0.4	1156.9	1163.73									
15.1	C40-0.4	1156										
15.2	C40-0.4	1174.8	1165.41	1223.7	2.68452	102.41	0.2247	13.4226	6.5774	1.123322	32.887	5.6166
16.1	C40-04	904.9										
16.2	C40-04	883.6	894.25									
17.1	C40-04	938.99										
17.2	C40-04	991.64	965.315									
18.1	C40-04	914.27										
18.2	C40-04	893.69	903.98	921.18	2.02087	38.529	0.0845	10.1044	9.8956	0.422621	49.478	2.1131
19.1	MagN	1739.1										
19.2	MagN	1807.6	1773.34									
20.1	MagN	1769.9										
20.1	MagN	1788.3	1779.05									
21.1	MagN	1790.7										
21.2	MagN	1786.8	1788.73	1780.4	3.90576	7.7799	0.0171	19.5288	0.4712	0.085337	2.3561	0.4267
22.1	N00-00	1690.3										
22.2	N00-00	1749	1719.65									
23.1	N00-00	1806.7										
23.2	N00-00	1739.7	1773.2									
24.1	N00-00	1723.9										
24.2	N00-00	1733.5	1728.72	1740.5	3.81833	28.663	0.0629	19.0916	0.9084	0.314399	4.5419	1.572

25.1	N00-0.4	1425.9										
25.2	N00-0.4	1459.7	1442.82									
26.1	N00-0.4	1448.7										
26.2	N00-0.4	1476.8	1462.73									
27.1	N00-0.4	1500.9										
27.2	N00-0.4	1536.2	1518.52	1474.7	3.23515	39.242	0.0861	16.1757	3.8243	0.430446	19.121	2.1522
28.1	N00-04	1328.2										
28.2	N00-04	1370.5	1349.34									
29.1	N00-04	1378.4										
29.2	N00-04	1402.6	1390.5									
31.1	N00-04	1381.7										
30.2	N00-04	1383.3	1382.51	1374.1	3.01451	21.823	0.0479	15.0725	4.9275	0.239376	24.637	1.1969

A11. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

95% Confidence

	diff	lwr	upr	p adj
C40-0.4-C40-04	302.51	215.7	389.319	0
N00-04-C40-04	452.9317	366.12	539.741	0
N00-0.4-C40-04	553.5067	466.7	640.316	0
C40-00-C40-04	606.305	519.5	693.114	0
N00-00-C40-04	819.3383	732.53	906.147	0
MagN-C40-04	859.1917	772.38	946.001	0
MagC-C40-04	860.8883	774.08	947.697	0
Blank(clay)-C40-04	901.7017	814.89	988.511	0
N00-04-C40-0.4	150.4217	63.613	237.231	4E-05
N00-0.4-C40-0.4	250.9967	164.19	337.806	0
C40-00-C40-0.4	303.795	216.99	390.604	0
N00-00-C40-0.4	516.8283	430.02	603.637	0
MagN-C40-0.4	556.6817	469.87	643.491	0
MagC-C40-0.4	558.3783	471.57	645.187	0
Blank(clay)-C40-0.4	599.1917	512.38	686.001	0
N00-0.4-N00-04	100.575	13.766	187.384	0.0126
C40-00-N00-04	153.3733	66.564	240.182	2E-05
N00-00-N00-04	366.4067	279.6	453.216	0
MagN-N00-04	406.26	319.45	493.069	0
MagC-N00-04	407.9567	321.15	494.766	0
Blank(clay)-N00-04	448.77	361.96	535.579	0
C40-00-N00-0.4	52.79833	-34.01	139.607	0.5639
N00-00-N00-0.4	265.8317	179.02	352.641	0
MagN-N00-0.4	305.685	218.88	392.494	0
MagC-N00-0.4	307.3817	220.57	394.191	0
Blank(clay)-N00-0.4	348.195	261.39	435.004	0
N00-00-C40-00	213.0333	126.22	299.842	0
MagN-C40-00	252.8867	166.08	339.696	0
MagC-C40-00	254.5833	167.77	341.392	0
Blank(clay)-C40-00	295.3967	208.59	382.206	0
MagN-N00-00	39.85333	-46.96	126.662	0.8518
MagC-N00-00	41.55	-45.26	128.359	0.8211
Blank(clay)-N00-00	82.36333	-4.446	169.172	0.075
MagC-MagN	1.696667	-85.11	88.5055	1
Blank(clay)-MagN	42.51	-44.3	129.319	0.8024
Blank(clay)-MagC	40.81333	-46	127.622	0.8348

	Blank (clay)	Mag C	Mag N	C40-00	C40-0.4	C40-04	N00-00	N00-0.4	N00-04
Blank (clay)		N.S.	N.S.	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05
Mag C	N.S.		N.S.	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05
Mag N	N.S.	N.S.		<0.05	<0.05	<0.05	N.S.	<0.05	<0.05
C40-00	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	N.S.	<0.05
C40-0.4	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
C40-04	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05
N00-00	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05		<0.05	<0.05
N00-0.4	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05	<0.05		N.S.
N00-04	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.	

Confidence Interval

	%removed	Stddev	Con int
Blank (clay)	0.02468007	0.4492	0.4264
MagC	2.2630713	2.1949	2.0835
C40-00	16.2255941	2.081	1.9753
C40-0.4	32.8871115	5.6166	5.3333
C40-04	49.4781536	2.1131	2.0038
MagN	2.35612431	0.4267	0.4046
N00-00	4.54186472	1.572	1.491
N00-0.4	19.121298	2.1522	2.0418
N00-04	24.6372943	1.1969	1.1301

A12. Experimental Data for Figure 7

1Hour

	DPM	Avg DPM	Avg DPM PPM		std dev DPM	Std dev ppı	%rem	%error	%rem
Blank	4958								
Blank	5038	4998.41							
Blank	5416								
Blank	5403	5409.43							
Blank	5597								
Blank	5525	5560.855	5322.9	2	262.573171	0.098658			
Blank(clay)	5353								-0.559
Blank(clay)	5419	5386.045							-1.814
Blank(clay)	5533								-3.955
Blank(clay)	5399	5465.99							-1.422
Blank(clay)	5355								-0.612
Blank(clay)	5360	5357.845	5403.29	2.03	69.169261	0.0259893	-1.51	1.2995	-0.701
C40-04	1866								64.94
C40-04	1941	1903.625							63.534
C40-04	1759								66.959
C40-04	1825	1792.05							65.707
C40-04	1697								68.128
C40-04	1714	1705.275	1800.32	0.68	94.5728282	0.0355343	66.18	1.7767	67.799
MagC	3641								31.592
MagC	3830	3735.71							28.044
MagC	4107								22.843
MagC	4206	4156.4							20.987
MagC	4029								24.313

MagC	4369	4198.845	4030.32	1.51	261.822697	0.098376	24.28	4.9188	17.922
MagN	4562								14.295
MagN	4665	4613.48							12.36
MagN	4740								10.954
MagN	4837	4788.305							9.133
MagN	4367								17.951
MagN	4478	4422.825	4608.2	1.73	173.097791	0.0650389	13.43	3.2519	15.867
N00-04	4037								24.16
N00-04	4071	4054.17							23.511
N00-04	3922								26.317
N00-04	3970	3946.19							25.411
N00-04	3967								25.473
N00-04	3961	3963.76	3988.04	1.5	55.1517557	0.0207225	25.08	1.0361	25.595

4 hour

	DPM	Avg DPM	Avg DPM	PPM	std dev DPM	Std dev ppm			
Blank	4494								
Blank	4614	4554.155							
Blank	5220								
Blank	5246	5232.895							
Blank	5319								
Blank	5400	5359.37	5048.81	2	390.080274	0.1545238			
Blank(clay)	5180								-2.604
Blank(clay)	5183	5181.545							-2.654
Blank(clay)	4992								1.1327
Blank(clay)	5043	5017.32							0.1146
Blank(clay)	5368								-6.315
Blank(clay)	5375	5371.14	5190	2.06	159.2178	0.0630715	-2.8	3.1536	-6.453

C40-04	2189								56.634
C40-04	2210	2199.565							56.234
C40-04	1955								61.27
C40-04	1939	1947.335							61.589
C40-04	1666								66.996
C40-04	1712	1689.22	1945.37	0.77	228.843788	0.0906526	61.47	4.5326	66.088
MagC	4884								3.2625
MagC	4917	4900.7							2.6045
MagC	4301								14.814
MagC	4214	4257.395							16.536
MagC	4511								10.653
MagC	4568	4539.545	4565.88	1.81	290.477648	0.1150678	9.565	5.7534	9.5206
MagN	5005								0.8595
MagN	5176	5090.665							-2.518
MagN	5257								-4.122
MagN	5297	5276.76							-4.908
MagN	5135								-1.698
MagN	5237	5185.54	5184.32	2.05	105.034691	0.0416077	-2.68	2.0804	-3.718
N00-04	3786								25.007
N00-04	3864	3825.15							23.466
N00-04	4004								20.696
N00-04	3986	3995							21.048
N00-04	3957								21.618
N00-04	4023	3990.305	3936.82	1.56	92.5056598	0.0366446	22.02	1.8322	20.313

12 hour

	DPM	Avg DPM	Avg DPM	PPM	std dev DPM	Std dev ppm			
Blank	4737								
Blank	4820	4778.675							
Blank	5051								
Blank	4685	4868.145							
Blank	5399								
Blank	5142	5270.375	4972.4	2	274.744801	0.110508			
Blank(clay)	4835								2.7584
Blank(clay)	4988	4911.445							-0.307
Blank(clay)	5142								-3.406
Blank(clay)	5166	5153.8							-3.89
Blank(clay)	5124								-3.056
Blank(clay)	5216	5169.94	5078.4	2.04	141.378904	0.0568655	-2.13	2.8433	-4.89
C40-04	1957								60.637
C40-04	1984	1970.635							60.1
C40-04	1882								62.141
C40-04	1879	1880.66							62.215
C40-04	2206								55.631
C40-04	2236	2221.08	2024.13	0.81	158.28844	0.0636668	59.29	3.1833	55.032
MagC	4839								2.6912
MagC	4913	4875.87							1.1913
MagC	4917								1.1071
MagC	4966	4941.855							0.1214
MagC	4972								0.0128
MagC	5002	4986.71	4934.81	1.98	58.0748043	0.0233589	0.756	1.1679	-0.588

MagN	5129								-3.148
MagN	5221	5174.81							-4.994
MagN	5133								-3.239
MagN	5260	5196.47							-5.774
MagN	5150								-3.57
MagN	5067	5108.67	5159.98	2.08	69.1854874	0.0278278	-3.77	1.3914	-1.911
N00-04	3791								23.751
N00-04	3870	3830.455							22.18
N00-04	3796								23.665
N00-04	3778	3786.83							24.021
N00-04	3761								24.359
N00-04	3713	3737.06	3784.78	1.52	51.1987884	0.0205932	23.88	1.0297	25.328

24 hour

	DPM	Avg DPM	Avg DPM	PPM	std dev DPM	Std dev ppm			
Blank	5351								
Blank	5414	5382.255							
Blank	5095								
Blank	5588	5341.1							
Blank	5050								
Blank	4999	5024.415	5249.26	2	235.840604	0.0898568			
Blank(clay)	5049								3.8098
Blank(clay)	4745	4896.975							9.6123
Blank(clay)	5436								-3.55
Blank(clay)	5312	5373.94							-1.2
Blank(clay)	5381								-2.509
Blank(clay)	5468	5424.475	5231.8	1.99	281.657469	0.1073133	0.333	5.3657	-4.167

C40-04	2028								61.372
C40-04	2193	2110.265							58.226
C40-04	2073								60.503
C40-04	2076	2074.67							60.451
C40-04	2001								61.887
C40-04	2023	2011.78	2065.57	0.79	69.0399894	0.0263047	60.65	1.3152	61.463
MagC	4883								6.9844
MagC	4996	4939.12							4.832
MagC	5011								4.5341
MagC	5157	5084.315							1.7503
MagC	5140								2.0831
MagC	5148	5144.105	5055.85	1.93	110.945584	0.042271	3.685	2.1135	1.9233
MagN	5194								1.0519
MagN	5384	5289.11							-2.57
MagN	5366								-2.228
MagN	5388	5377.335							-2.652
MagN	5439								-3.61
MagN	5510	5474.28	5380.24	2.05	105.037603	0.04002	-2.5	2.001	-4.964
N00-04	3948								24.798
N00-04	3544	3745.67							32.489
N00-04	4077								22.341
N00-04	4173	4124.58							20.51
N00-04	4058								22.686
N00-04	4038	4048.295	3972.85	1.51	222.245014	0.0846768	24.32	4.2338	23.071

A13. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

Cationic POLYMERS
95% Confidence

	diff	lwr	upr	p adj
Blank(clay)12HR-Blank(clay)4HR	0.665	-7.34318	8.67298	1
Blank(clay)1HR-Blank(clay)4HR	1.286	-6.72184	9.29432	1
Blank(clay)24HR-Blank(clay)4HR	3.129	-4.87886	11.1373	0.92
MagC12HR-Blank(clay)4HR	3.553	-4.45557	11.5606	0.83
MagC24HR-Blank(clay)4HR	6.481	-1.52696	14.4892	0.08
MagC4HR-Blank(clay)4HR	12.36	4.353684	20.3698	0
MagC1HR-Blank(clay)4HR	27.08	19.07191	35.0881	0
C40-0412HR-Blank(clay)4HR	62.09	54.0813	70.0975	0
C40-0424HR-Blank(clay)4HR	63.45	55.43873	71.4549	0
C40-044HR-Blank(clay)4HR	64.27	56.25717	72.2733	0
C40-041HR-Blank(clay)4HR	68.97	60.96641	76.9826	0
Blank(clay)1HR-Blank(clay)12HR	0.621	-7.38674	8.62942	1
Blank(clay)24HR-Blank(clay)12HR	2.464	-5.54376	10.4724	0.99
MagC12HR-Blank(clay)12HR	2.888	-5.12047	10.8957	0.95
MagC24HR-Blank(clay)12HR	5.816	-2.19186	13.8243	0.18
MagC4HR-Blank(clay)12HR	11.7	3.688784	19.7049	0
MagC1HR-Blank(clay)12HR	26.42	18.40701	34.4232	0
C40-0412HR-Blank(clay)12HR	61.42	53.4164	69.4326	0
C40-0424HR-Blank(clay)12HR	62.78	54.77383	70.79	0
C40-044HR-Blank(clay)12HR	63.6	55.59227	71.6084	0
C40-041HR-Blank(clay)12HR	68.31	60.30151	76.3177	0
Blank(clay)24HR-Blank(clay)1HR	1.843	-6.1651	9.85106	1
MagC12HR-Blank(clay)1HR	2.266	-5.74181	10.2743	0.99
MagC24HR-Blank(clay)1HR	5.195	-2.8132	13.203	0.32
MagC4HR-Blank(clay)1HR	11.08	3.067444	19.0836	0
MagC1HR-Blank(clay)1HR	25.79	17.78567	33.8018	0
C40-0412HR-Blank(clay)1HR	60.8	52.79506	68.8112	0
C40-0424HR-Blank(clay)1HR	62.16	54.15249	70.1687	0
C40-044HR-Blank(clay)1HR	62.98	54.97093	70.9871	0
C40-041HR-Blank(clay)1HR	67.69	59.68017	75.6963	0
MagC12HR-Blank(clay)24HR	0.423	-7.58479	8.43137	1
MagC24HR-Blank(clay)24HR	3.352	-4.65618	11.36	0.88
MagC4HR-Blank(clay)24HR	9.233	1.224464	17.2406	0

MagC1HR-Blank(clay)24HR	23.95	15.94269	31.9589	0
C40-0412HR-Blank(clay)24HR	58.96	50.95208	66.9682	0
C40-0424HR-Blank(clay)24HR	60.32	52.30951	68.3257	0
C40-044HR-Blank(clay)24HR	61.14	53.12795	69.1441	0
C40-041HR-Blank(clay)24HR	65.85	57.83719	73.8534	0
MagC24HR-MagC12HR	2.929	-5.07947	10.9367	0.95
MagC4HR-MagC12HR	8.809	0.801177	16.8173	0
MagC1HR-MagC12HR	23.53	15.5194	31.5356	0
C40-0412HR-MagC12HR	58.54	50.52879	66.545	0
C40-0424HR-MagC12HR	59.89	51.88622	67.9024	0
C40-044HR-MagC12HR	60.71	52.70466	68.7208	0
C40-041HR-MagC12HR	65.42	57.4139	73.4301	0
MagC4HR-MagC24HR	5.881	-2.12744	13.8887	0.16
MagC1HR-MagC24HR	20.6	12.59078	28.6069	0
C40-0412HR-MagC24HR	55.61	47.60018	63.6163	0
C40-0424HR-MagC24HR	56.97	48.9576	64.9738	0
C40-044HR-MagC24HR	57.78	49.77605	65.7922	0
C40-041HR-MagC24HR	62.49	54.48528	70.5014	0
MagC1HR-MagC4HR	14.72	6.710141	22.7263	0
C40-0412HR-MagC4HR	49.73	41.71954	57.7357	0
C40-0424HR-MagC4HR	51.09	43.07696	59.0931	0
C40-044HR-MagC4HR	51.9	43.8954	59.9116	0
C40-041HR-MagC4HR	56.61	48.60464	64.6208	0
C40-0412HR-MagC1HR	35.01	27.00131	43.0175	0
C40-0424HR-MagC1HR	36.37	28.35874	44.3749	0
C40-044HR-MagC1HR	37.19	29.17718	45.1933	0
C40-041HR-MagC1HR	41.89	33.88642	49.9026	0
C40-0424HR-C40-0412HR	1.357	-6.65066	9.36551	1
C40-044HR-C40-0412HR	2.176	-5.83221	10.184	0.99
C40-041HR-C40-0412HR	6.885	-1.12298	14.8932	0.05
C40-044HR-C40-0424HR	0.818	-7.18964	8.82653	1
C40-041HR-C40-0424HR	5.528	-2.4804	13.5358	0.24
C40-041HR-C40-044HR	4.709	-3.29885	12.7173	0.47

NONIONIC POLYMERS
95% Confidence

	diff	lwr	upr
Blank(clay)4HR-MagN12HR	0.976	-5.381	7.3332
MagN4HR-MagN12HR	1.088	-5.269	7.4457
MagN24HR-MagN12HR	1.277	-5.08	7.6345
Blank(clay)12HR-MagN12HR	1.641	-4.716	7.9981
Blank(clay)1HR-MagN12HR	2.262	-4.095	8.6195
Blank(clay)24HR-MagN12HR	4.105	-2.252	10.462
MagN1HR-MagN12HR	17.2	10.842	23.557
N00-044HR-MagN12HR	25.8	19.44	32.155
N00-0412HR-MagN12HR	27.66	21.299	34.014
N00-0424HR-MagN12HR	28.09	21.731	34.446
N00-041HR-MagN12HR	28.85	22.493	35.207
MagN4HR-Blank(clay)4HR	0.113	-6.245	6.4698
MagN24HR-Blank(clay)4HR	0.301	-6.056	6.6586
Blank(clay)12HR-Blank(clay)4HR	0.665	-5.692	7.0222
Blank(clay)1HR-Blank(clay)4HR	1.286	-5.071	7.6435
Blank(clay)24HR-Blank(clay)4HR	3.129	-3.228	9.4865
MagN1HR-Blank(clay)4HR	16.22	9.8661	22.581
N00-044HR-Blank(clay)4HR	24.82	18.464	31.179
N00-0412HR-Blank(clay)4HR	26.68	20.323	33.038
N00-0424HR-Blank(clay)4HR	27.11	20.755	33.47
N00-041HR-Blank(clay)4HR	27.87	21.517	34.232
MagN24HR-MagN4HR	0.189	-6.168	6.5461
Blank(clay)12HR-MagN4HR	0.552	-5.805	6.9097
Blank(clay)1HR-MagN4HR	1.174	-5.184	7.531
Blank(clay)24HR-MagN4HR	3.017	-3.341	9.374
MagN1HR-MagN4HR	16.11	9.7536	22.468
N00-044HR-MagN4HR	24.71	18.352	31.066
N00-0412HR-MagN4HR	26.57	20.211	32.926
N00-0424HR-MagN4HR	27	20.643	33.357
N00-041HR-MagN4HR	27.76	21.404	34.119
Blank(clay)12HR-MagN24HR	0.364	-5.994	6.7209
Blank(clay)1HR-MagN24HR	0.985	-5.372	7.3422
Blank(clay)24HR-MagN24HR	2.828	-3.529	9.1852
MagN1HR-MagN24HR	15.92	9.5648	22.279
N00-044HR-MagN24HR	24.52	18.163	30.877
N00-0412HR-MagN24HR	26.38	20.022	32.737
N00-0424HR-MagN24HR	26.81	20.454	33.169
N00-041HR-MagN24HR	27.57	21.216	33.93

Blank(clay)1HR-Blank(clay)12HR	0.621	-5.736	6.9786	1
Blank(clay)24HR-Blank(clay)12HR	2.464	-3.893	8.8216	0.9244
MagN1HR-Blank(clay)12HR	15.56	9.2012	21.916	0
N00-044HR-Blank(clay)12HR	24.16	17.799	30.514	0
N00-0412HR-Blank(clay)12HR	26.02	19.659	32.373	0
N00-0424HR-Blank(clay)12HR	26.45	20.09	32.805	0
N00-041HR-Blank(clay)12HR	27.21	20.852	33.567	0
Blank(clay)24HR-Blank(clay)1HR	1.843	-4.514	8.2003	0.9909
MagN1HR-Blank(clay)1HR	14.94	8.5799	21.294	0
N00-044HR-Blank(clay)1HR	23.54	17.178	29.892	0
N00-0412HR-Blank(clay)1HR	25.39	19.037	31.752	0
N00-0424HR-Blank(clay)1HR	25.83	19.469	32.184	0
N00-041HR-Blank(clay)1HR	26.59	20.231	32.945	0
MagN1HR-Blank(clay)24HR	13.09	6.7369	19.451	0
N00-044HR-Blank(clay)24HR	21.69	15.335	28.049	0
N00-0412HR-Blank(clay)24HR	23.55	17.194	29.909	0
N00-0424HR-Blank(clay)24HR	23.98	17.626	30.341	0
N00-041HR-Blank(clay)24HR	24.75	18.388	31.102	0
N00-044HR-MagN1HR	8.598	2.2407	14.955	9E-05
N00-0412HR-MagN1HR	10.46	4.1001	16.815	1E-06
N00-0424HR-MagN1HR	10.89	4.5319	17.246	4E-07
N00-041HR-MagN1HR	11.65	5.2936	18.008	1E-07
N00-0412HR-N00-044HR	1.859	-4.498	8.2167	0.9902
N00-0424HR-N00-044HR	2.291	-4.066	8.6485	0.9532
N00-041HR-N00-044HR	3.053	-3.304	9.4102	0.7533
N00-0424HR-N00-0412HR	0.432	-5.925	6.7891	1
N00-041HR-N00-0412HR	1.193	-5.164	7.5508	0.9998
N00-041HR-N00-0424HR	0.762	-5.596	7.119	1

	Clay (1hr)	Clay (4hr)	Clay (12hr)	Clay (24hr)	Mag C (1hr)	Mag C (4hr)	Mag C (12hr)	Mag C (24hr)	C40-04 (1hr)	C40-04 (4hr)	C40-04 (12hr)
Clay (1hr)		N.S.	N.S.	N.S.	<0.05	<0.05	N.S.	N.S.	<0.05	<0.05	<0.05
Clay (4hr)	N.S.		N.S.	N.S.	<0.05	<0.05	N.S.	N.S.	<0.05	<0.05	<0.05
Clay (12hr)	N.S.	N.S.		N.S.	<0.05	<0.05	N.S.	N.S.	<0.05	<0.05	<0.05
Clay (24hr)	N.S.	N.S.	N.S.		<0.05	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05
Mag C (1hr)	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mag C (4hr)	<0.05	<0.05	<0.05	N.S.	<0.05		N.S.	N.S.	<0.05	<0.05	<0.05
Mag C (12hr)	N.S.	N.S.	N.S.	N.S.	<0.05	N.S.		N.S.	<0.05	<0.05	<0.05
Mag C (24hr)	N.S.	N.S.	N.S.	N.S.	<0.05	N.S.	N.S.		<0.05	<0.05	<0.05
C40-04 (1hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		N.S.	N.S.
C40-04 (4hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.		N.S.
C40-04 (12hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.	N.S.	
C40-04 (24hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.	N.S.	N.S.

	Clay (1hr)	Clay (4hr)	Clay (12hr)	Clay (24hr)	Mag N (1hr)	Mag N (4hr)	Mag N (12hr)	Mag N (24hr)	N00-04 (1hr)	N00-04 (4hr)	N00-04 (12hr)
Clay (1hr)		N.S.	N.S.	N.S.	<0.05	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05
Clay (4hr)	N.S.		N.S.	N.S.	<0.05	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05
Clay (12hr)	N.S.	N.S.		N.S.	<0.05	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05
Clay (24hr)	N.S.	N.S.	N.S.		<0.05	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05
Mag N (1hr)	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mag N (4hr)	N.S.	N.S.	N.S.	N.S.	<0.05		N.S.	N.S.	<0.05	<0.05	<0.05
Mag N (12hr)	N.S.	N.S.	N.S.	N.S.	<0.05	N.S.		N.S.	<0.05	<0.05	<0.05
Mag N (24hr)	N.S.	N.S.	N.S.	N.S.	<0.05	N.S.	N.S.		<0.05	<0.05	<0.05
N00-04 (1hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		N.S.	N.S.
N00-04 (4hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.		N.S.
N00-04 (12hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.	N.S.	
N00-04 (24hr)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.	N.S.	N.S.

Confidence Interval	1	4	12	24
Blank(clay)	1.233604	2.994742	2.698924	5.094908
C40-04	1.687255	4.303844	3.022757	1.248799
MagC	4.670412	5.460526	1.108249	2.006625
MagN	3.088189	1.975286	1.320972	1.900263
N00-04	0.983844	1.739771	0.9771967	3.922082

A13. Experimental Data for Figure 8

Sample	Desc.	DPM	AVG/sam	avg/rep	conc/ml	stddev	error/ml	conc/5ml	AT rem	error/5ml	% remo	%error
1.1	Blank	5728										
1.2	Blank	5865	5796.51									
2.1	Blank	6712										
2.2	Blank	6223	6467.83									
3.1	Blank	5860										
3.2	Blank	5985	5922.36	6062.2	0.4	356.8	0.0235	2		0.117728		
4.1	Blank (c	5747										
4.2	Blank (c	5786	5766.49									
5.1	Blank (c	5571										
5.2	Blank (c	5621	5596.38									
6.1	Blank (c	5655										
6.2	Blank (c	5738	5696.86	5686.6	0.3752	85.52	0.0056	1.87607	0.1239	0.028213	6.197	1.411
7.1	Mag C .	5532										
7.2	Mag C .	5778	5654.76									
8.1	Mag C .	5662										
8.2	Mag C .	5562	5612.25									
9.1	Mag C .	5442										
9.2	Mag C .	5586	5513.87	5593.6	0.3691	72.27	0.0048	1.8454	0.1546	0.023842	7.73	1.192
10.1	Mag C .	5564										
10.2	Mag C .	5580	5571.66									
11.1	Mag C .	5474										
11.2	Mag C .	5654	5564.02									
12.1	Mag C .	5488										
12.2	Mag C .	5628	5558.06	5564.6	0.3672	6.815	0.0004	1.83582	0.1642	0.002248	8.209	0.112

13.1 Mag C .	5512										
13.2 Mag C .	5727	5619.71									
14.1 Mag C .	5557										
14.2 Mag C .	5818	5687.77									
15.1 Mag C .	5618										
15.2 Mag C .	5688	5652.88	5653.5	0.373	34.03	0.0022	1.86514	0.1349	0.011228	6.743	0.561
16.1 Mag C .	5461										
16.2 Mag C .	5691	5576.28									
17.1 Mag C .	5613										
17.2 Mag C .	5838	5725.18									
18.1 Mag C .	5595										
18.2 Mag C .	5688	5641.91	5647.8	0.3727	74.63	0.0049	1.86327	0.1367	0.02462	6.836	1.231
19.1 Mag C '	5405										
19.2 Mag C '	5464	5434.43									
20.1 Mag C '	5618										
20.1 Mag C '	5714	5666.02									
21.1 Mag C '	5584										
21.2 Mag C '	5717	5650.75	5583.7	0.3684	129.5	0.0085	1.84214	0.1579	0.042732	7.893	2.137
22.1 C40-04	5283										
22.2 C40-04	5589	5436									
23.1 C40-04	5594										
23.2 C40-04	5603	5598.58									
24.1 C40-04	5150										
24.2 C40-04	5444	5297.31	5444	0.3592	150.8	0.0099	1.79603	0.204	0.049749	10.2	2.487

25.1	C40-04	5157										
25.2	C40-04	5264	5210.41									
26.1	C40-04	5263										
26.2	C40-04	5514	5388.21									
27.1	C40-04	5163										
27.2	C40-04	5480	5321.69	5306.8	0.3502	89.83	0.0059	1.75076	0.2492	0.029637	12.46	1.482
28.1	C40-04	5333										
28.2	C40-04	5533	5432.99									
29.1	C40-04	5487										
29.2	C40-04	5742	5614.86									
31.1	C40-04	5566										
31.2	C40-04	5555	5560.65	5536.2	0.3653	93.37	0.0062	1.82644	0.1736	0.030804	8.678	1.54
32.1	C40-04	5302										
32.2	C40-04	5437	5369.36									
33.1	C40-04	5497										
33.2	C40-04	5538	5517.13									
34.1	C40-04	5487										
34.2	C40-04	5572	5529.78	5472.1	0.3611	89.19	0.0059	1.8053	0.1947	0.029426	9.735	1.471
35.1	C40-04	3278										
35.2	C40-04	3185	3231.78									
36.1	C40-04	3038										
36.2	C40-04	2984	3011.38									
37.1	C40-04	3248										
37.2	C40-04	3179	3213.88	3152.3	0.208	122.4	0.0081	1.04	0.96	0.040385	48	2.019

A15. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

95% Confidence

	diff	lwr	upr	p adj
C40-04(0.05)-C40-04(1.0)	2154	1910	2399	0
C40-04(0.01)-C40-04(1.0)	2292	2047	2536.19	0
C40-04(0.5)-C40-04(1.0)	2320	2075	2564.32	0
C40-04(0.1)-C40-04(1.0)	2384	2139	2628.39	0
MagC(0.05)-C40-04(1.0)	2412	2168	2656.81	0
MagC(1.0)-C40-04(1.0)	2431	2187	2675.96	0
MagC(0.01)-C40-04(1.0)	2441	2197	2685.86	0
MagC(0.5)-C40-04(1.0)	2495	2251	2740.02	0
MagC(0.1)-C40-04(1.0)	2501	2257	2745.68	0
C40-04(0.01)-C40-04(0.05)	137.2	-107	381.767	0.6966
C40-04(0.5)-C40-04(0.05)	165.3	-79.3	409.892	0.4461
C40-04(0.1)-C40-04(0.05)	229.4	-15.2	473.969	0.0831
MagC(0.05)-C40-04(0.05)	257.8	13.23	502.382	0.0313
MagC(1.0)-C40-04(0.05)	277	32.39	521.539	0.0152
MagC(0.01)-C40-04(0.05)	286.9	42.28	531.432	0.0103
MagC(0.5)-C40-04(0.05)	341	96.44	585.592	0.0011
MagC(0.1)-C40-04(0.05)	346.7	102.1	591.259	0.0008
C40-04(0.5)-C40-04(0.01)	28.13	-216	272.701	1
C40-04(0.1)-C40-04(0.01)	92.2	-152	336.777	0.9603
MagC(0.05)-C40-04(0.01)	120.6	-124	365.191	0.8258
MagC(1.0)-C40-04(0.01)	139.8	-105	384.347	0.6743
MagC(0.01)-C40-04(0.01)	149.7	-94.9	394.241	0.5858
MagC(0.5)-C40-04(0.01)	203.8	-40.8	448.401	0.1792
MagC(0.1)-C40-04(0.01)	209.5	-35.1	454.067	0.1527
C40-04(0.1)-C40-04(0.5)	64.08	-180	308.652	0.9968
MagC(0.05)-C40-04(0.5)	92.49	-152	337.066	0.9595
MagC(1.0)-C40-04(0.5)	111.6	-133	356.222	0.8813
MagC(0.01)-C40-04(0.5)	121.5	-123	366.116	0.8195
MagC(0.5)-C40-04(0.5)	175.7	-68.9	420.276	0.3604
MagC(0.1)-C40-04(0.5)	181.4	-63.2	425.942	0.3174
MagC(0.05)-C40-04(0.1)	28.41	-216	272.989	1
MagC(1.0)-C40-04(0.1)	47.57	-197	292.146	0.9997

MagC(0.01)-C40-04(0.1)	57.46	-187	302.039	0.9986
MagC(0.5)-C40-04(0.1)	111.6	-133	356.199	0.8815
MagC(0.1)-C40-04(0.1)	117.3	-127	361.866	0.8478
MagC(1.0)-MagC(0.05)	19.16	-225	263.732	1
MagC(0.01)-MagC(0.05)	29.05	-216	273.626	1
MagC(0.5)-MagC(0.05)	83.21	-161	327.786	0.9795
MagC(0.1)-MagC(0.05)	88.88	-156	333.452	0.9685
MagC(0.01)-MagC(1.0)	9.893	-235	254.469	1
MagC(0.5)-MagC(1.0)	64.05	-181	308.629	0.9968
MagC(0.1)-MagC(1.0)	69.72	-175	314.296	0.994
MagC(0.5)-MagC(0.01)	54.16	-190	298.736	0.9991
MagC(0.1)-MagC(0.01)	59.83	-185	304.402	0.9981
MagC(0.1)-MagC(0.5)	5.667	-239	250.242	1

Confidence Interval norm

	1	0.5	0.1	0.05	0.01
Mag C	2.028467	1.16903	0.533137	0.1067	1.13199
C40-04	1.917357	1.396	1.462471	1.4064	2.3618

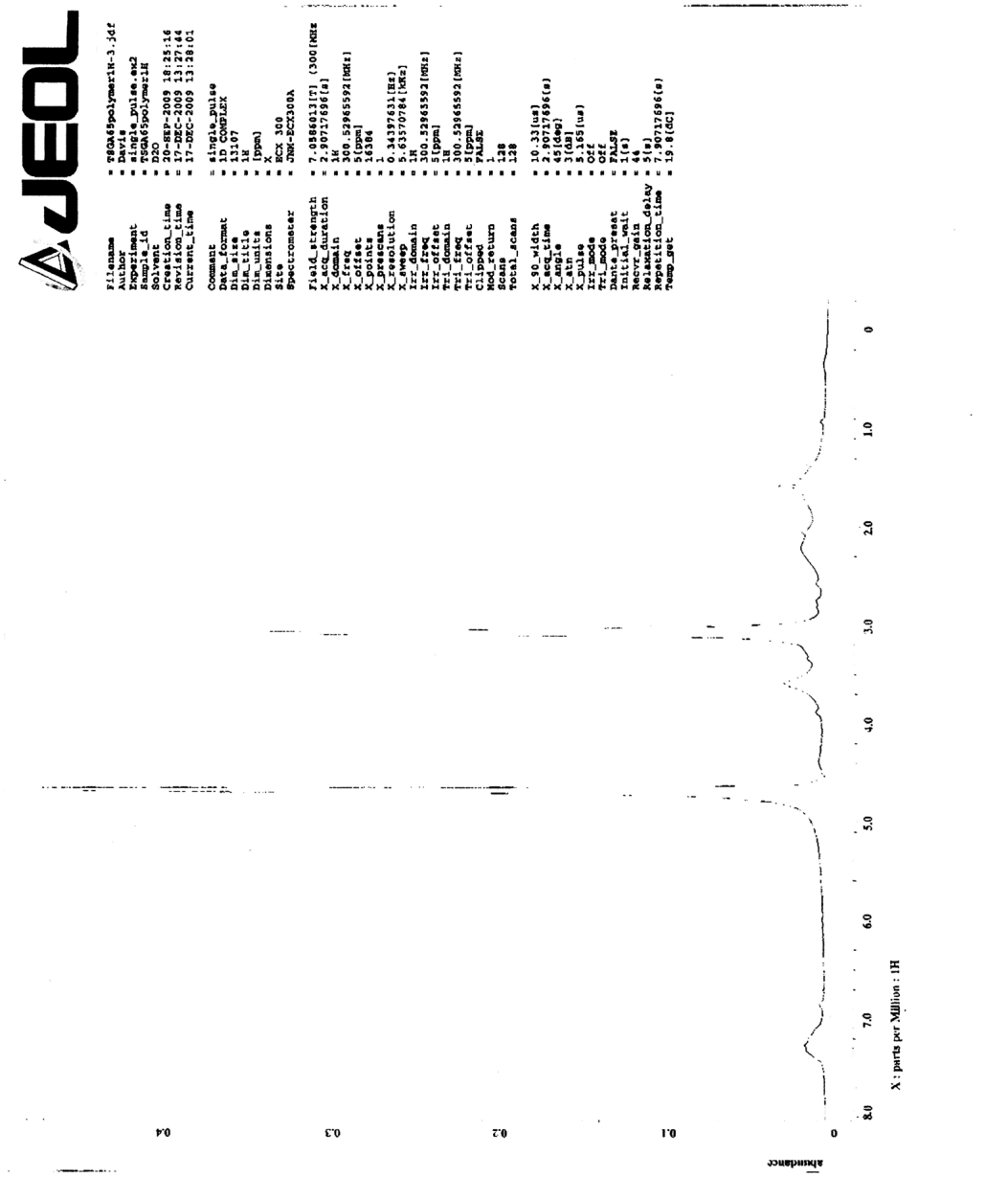
	Blank(clay)	MagC.01	MagC.05	MagC.1	MagC.5	MagC1	C40-04.01	C40-04.05	C40-04.1	C40-04.5	C40-041
Blank(clay)		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	<0.05	N.S.	N.S.	<0.05
MagC.01	N.S.		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	<0.05
MagC.05	N.S.	N.S.		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	<0.05
MagC.1	N.S.	N.S.	N.S.		N.S.	N.S.	N.S.	<0.05	N.S.	N.S.	<0.05
MagC.5	N.S.	N.S.	N.S.	N.S.		N.S.	N.S.	<0.05	N.S.	N.S.	<0.05
MagC1	N.S.	N.S.	N.S.	N.S.	N.S.		N.S.	N.S.	N.S.	N.S.	<0.05
C40-04.01	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.		N.S.	N.S.	N.S.	<0.05
C40-04.05	<0.05	N.S.	N.S.	<0.05	<0.05	N.S.	N.S.		N.S.	N.S.	<0.05
C40-04.1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.		N.S.	<0.05
C40-04.5	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.		<0.05
C40-041	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

APPENDIX B

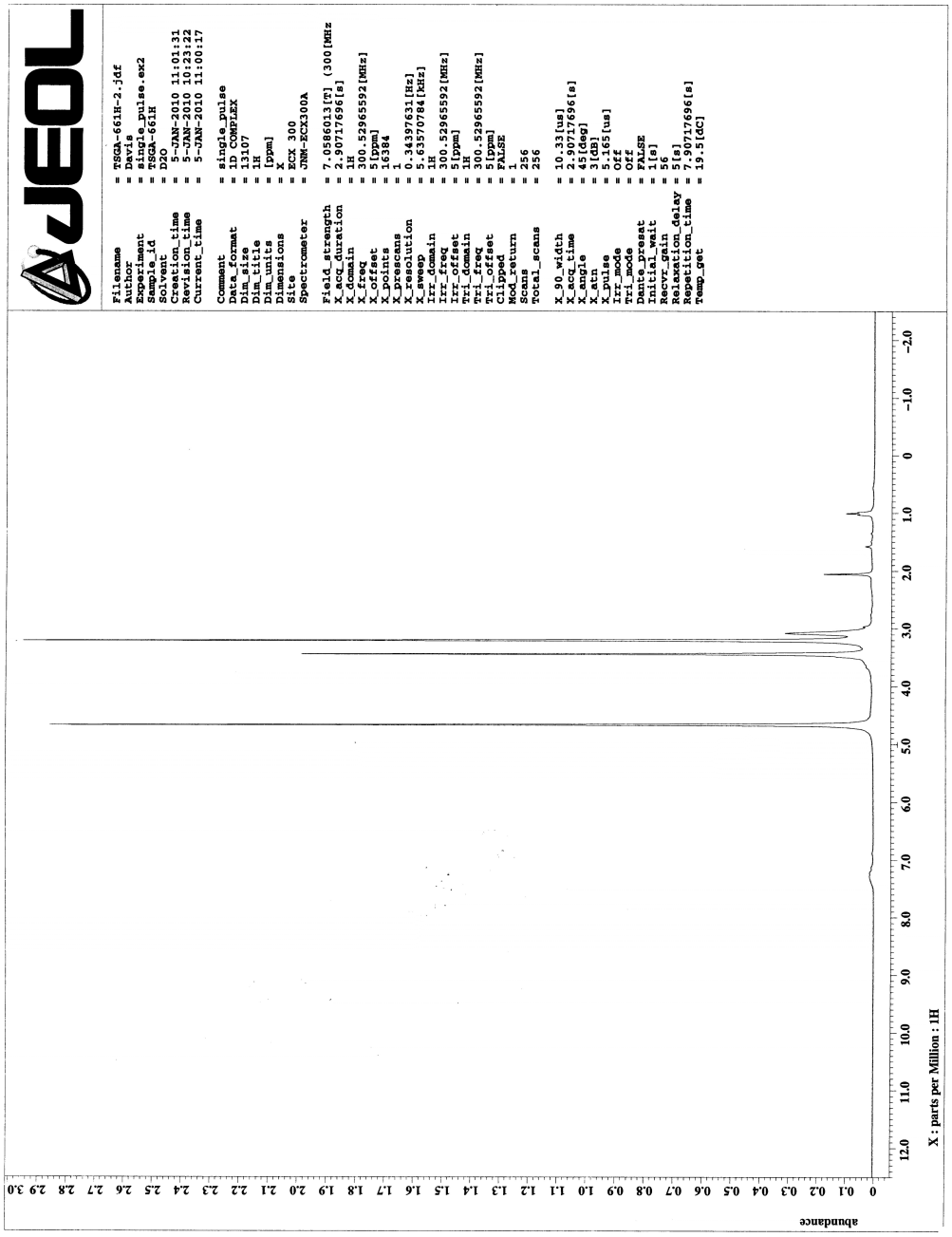
EXPERIMENTAL DATA AND ANOVA ANALYSIS FOR CHAPTER III

ANOVA analysis was accomplished using R Stats:R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing,Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

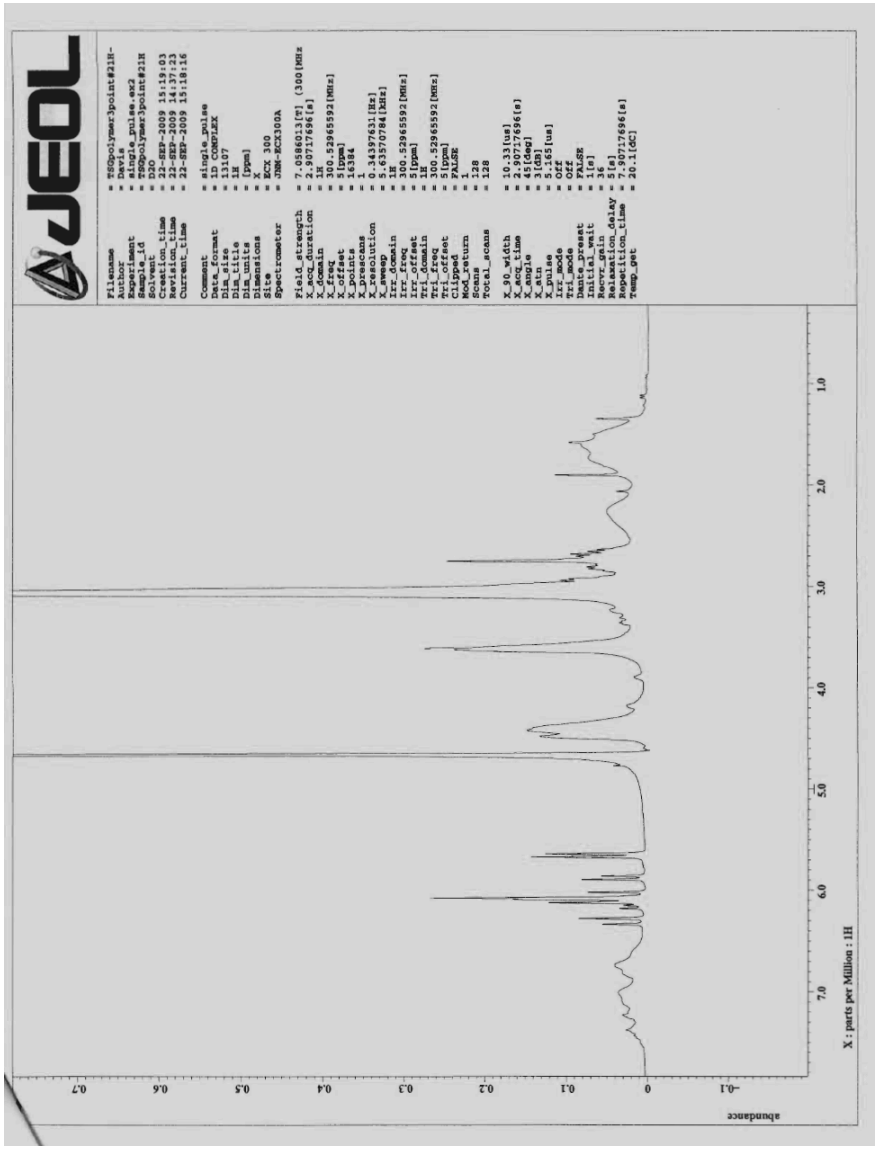
B1. NMR of C40-20(2pt)



B2. NMR of C40-40(2pt)



B3. NMR of C40-20 (3pt)



B4. Experimental data for Figure 10 (0.25 mg/L P) .

sample	polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error
1.1	standard	0.017397					
1.1r	standard	0.017478					
1.2	standard	0.016591					
1.2r	standard	0.016936					
1.3	standard	0.016878					
1.3r	standard	0.016726	0.017001108	0.000359848	0.249151236		
2.1	Clay	0.015483					
2.2	Clay	0.016572					
2.3	Clay	0.016507	0.016187272	0.000610663	0.237224468	4.786959151	3.591899583
3.1	MagN	0.017100					
3.2	MagN	0.016979					
3.2	MagN	0.016637	0.016905716	0.00024023	0.247753271	0.56109087	1.413028083
4.1	MagC	0.015997					
4.2	MagC	0.016076					
4.3	MagC	0.016240	0.016104394	0.000123685	0.236009895	5.274443709	0.727512747
5.1	C40-00	0.015387					
5.2	C40-00	0.015951					
5.3	C40-00	0.015737	0.015691777	0.000284446	0.229962998	7.701442341	1.673101308
6.1	C40-20(2pt)	0.016413					
6.2	C40-20(2pt)	0.016239					
6.3	C40-20(2pt)	0.016325	0.015941816	0.000473787	0.233627317	6.230721232	2.78680284
7.1	C40-40(2pt)	0.015073					
7.2	C40-40(2pt)	0.015500					
7.3	C40-40(2pt)	0.015457	0.015588729	0.000527351	0.22845282	8.307571124	3.101860906
8.1	C40-20(3pt)	0.016251					
8.2	C40-20(3pt)	0.016091					
8.3	C40-20(3pt)	0.016127	0.0161564	8.39397E-05	0.236772036	4.968548619	0.493731028

B4. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-00-C40-40(2pt)	0.000348	-4.66E-04	0.001163	0.761927
MagC-C40-40(2pt)	0.000761	-5.33E-05	0.001575	0.074116
C40-20(3pt)-C40-40(2pt)	0.000813	-1.27E-06	0.001627	0.050475
Clay-C40-40(2pt)	0.000844	2.97E-05	0.001658	0.040008
C40-20(2pt)-C40-40(2pt)	0.000982	1.68E-04	0.001797	0.013963
MagN-C40-40(2pt)	0.001562	7.48E-04	0.002376	0.000204
MagC-C40-00	0.000413	-4.02E-04	0.001227	0.608914
C40-20(3pt)-C40-00	0.000465	-3.50E-04	0.001279	0.483519
Clay-C40-00	0.000496	-3.19E-04	0.00131	0.413629
C40-20(2pt)-C40-00	0.000634	-1.80E-04	0.001448	0.180393
MagN-C40-00	0.001214	3.99E-04	0.002028	0.002424
C40-20(3pt)-MagC	0.000052	-7.62E-04	0.000866	0.999987
Clay-MagC	0.000083	-7.31E-04	0.000897	0.9998
C40-20(2pt)-MagC	0.000221	-5.93E-04	0.001036	0.961389
MagN-MagC	0.000801	-1.33E-05	0.001615	0.055193
Clay-C40-20(3pt)	0.000031	-7.83E-04	0.000845	0.999999
C40-20(2pt)-C40-20(3pt)	0.000169	-6.45E-04	0.000984	0.989663
MagN-C40-20(3pt)	0.000749	-6.53E-05	0.001563	0.080883
C40-20(2pt)-Clay	0.000138	-6.76E-04	0.000953	0.996458
MagN-Clay	0.000718	-9.63E-05	0.001532	0.101093
MagN-C40-20(2pt)	0.00058	-2.35E-04	0.001394	0.255537

	Clay	**MagN**	**MagC**	**C40-00**	**C40-20(2pt)**	**C40-40(2pt)**	**C40-20(3pt)**
Clay	N.A.	N.A.	N.A.	N.A.	N.A.	<0.05	N.A.
MagN	N.A.	N.A.	N.A.	<0.001	N.A.	<0.001	N.A.
MagC	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
C40-00	N.A.	<0.001	N.A.	N.A.	N.A.	N.A.	N.A.
C40-20(2pt)	N.A.	N.A.	N.A.	N.A.	N.A.	<0.05	N.A.
C40-40(2pt)	<0.05	<0.001	N.A.	N.A.	<0.05	N.A.	N.A.

B4. Experimental data for Figure 10 (0.5 mg/L P) .

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error
standard	0.030965333					
standard	0.032236199					
standard	0.031756833					
standard	0.031265383					
standard	0.030388299					
standard	0.031582299	0.03137	0.00065	0.45966		
Clay	0.031238266					
Clay	0.029984866					
Clay	0.030300933	0.03051	0.00065	0.44710	2.73452	2.07825
MagN	0.030111966					
MagN	0.030159599					
MagN	0.029618083	0.02996	0.00030	0.43911	4.47147	0.95595
MagC	0.030544899					
MagC	0.029688199					
MagC	0.029432483	0.02989	0.00058	0.43802	4.70959	1.85756
C40-00	0.030201483					
C40-00	0.027899916					
C40-00	0.028537599	0.02888	0.00119	0.42323	7.92603	3.78853
C40-20(2pt)	0.029572016					
C40-20(2pt)	0.027203033					
C40-20(2pt)	0.029382616	0.02872	0.00132	0.42088	8.43756	4.19716
C40-40(2pt)	0.026505033					
C40-40(2pt)	0.026743716					
C40-40(2pt)	0.026344916	0.02653	0.00020	0.38882	15.41333	0.63982
C40-20(3pt)	0.028661833					
C40-20(3pt)	0.028690333					
C40-20(3pt)	0.029093699	0.02882	0.00024	0.42229	8.13128	0.77005

B4. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-20(2pt)-C40-40(2pt)	2.19E-03	5.48E-05	0.004321	0.042751
C40-20(3pt)-C40-40(2pt)	2.28E-03	1.51E-04	0.004417	0.032418
C40-00-C40-40(2pt)	2.35E-03	2.15E-04	0.004482	0.026902
MagC-C40-40(2pt)	3.36E-03	1.22E-03	0.005491	0.00147
MagN-C40-40(2pt)	3.43E-03	1.30E-03	0.005565	0.001194
Clay-C40-40(2pt)	3.98E-03	1.84E-03	0.00611	0.000275
C40-20(3pt)-C40-20(2pt)	9.61E-05	-2.04E-03	0.002229	0.999998
C40-00-C40-20(2pt)	1.60E-04	-1.97E-03	0.002294	0.999966
MagC-C40-20(2pt)	1.17E-03	-9.64E-04	0.003303	0.526924
MagN-C40-20(2pt)	1.24E-03	-8.89E-04	0.003377	0.460019
Clay-C40-20(2pt)	1.79E-03	-3.44E-04	0.003922	0.129505
C40-00-C40-20(3pt)	6.44E-05	-2.07E-03	0.002198	1
MagC-C40-20(3pt)	1.07E-03	-1.06E-03	0.003206	0.616272
MagN-C40-20(3pt)	1.15E-03	-9.85E-04	0.003281	0.546603
Clay-C40-20(3pt)	1.69E-03	-4.40E-04	0.003826	0.166369
MagC-C40-00	1.01E-03	-1.12E-03	0.003142	0.676177
MagN-C40-00	1.08E-03	-1.05E-03	0.003217	0.606618
Clay-C40-00	1.63E-03	-5.05E-04	0.003762	0.195777
MagN-MagC	7.47E-05	-2.06E-03	0.002208	1
Clay-MagC	6.19E-04	-1.51E-03	0.002753	0.947762
Clay-MagN	5.45E-04	-1.59E-03	0.002678	0.971228

	Clay	**MagN**	**MagC**	**C40-00**	**C40-20(2pt**	**C40-40(2pt**	**C40-20(3pt**
Clay		N.A.	N.A.	N.A.	N.A.	<0.05	N.A.
MagN	N.A.		N.A.	N.A.	N.A.	<0.05	N.A.
MagC	N.A.	N.A.		N.A.	N.A.	<0.05	N.A.
C40-00	N.A.	N.A.	N.A.		N.A.	<0.05	N.A.
C40-20(2pt)	N.A.	N.A.	N.A.	N.A.		<0.05	N.A.
C40-40(2pt)	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05
C40-20(3pt)	N.A.	N.A.	N.A.	N.A.	N.A.	<0.05	

B4. Experimental data for Figure 10 (1.0 mg/L P) .

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error
standard	0.062863798					
standard	0.062697082					
standard	0.063064082					
standard	0.063448365					
standard	0.063463565					
standard	0.063278032	0.06314	0.00032	0.92526		
Clay	0.060709532					
Clay	0.061217732					
Clay	0.060861032	0.06093	0.00026	0.89292	3.49467	0.41326
MagN	0.060442332					
MagN	0.061244315					
MagN	0.062616398	0.06143	0.00110	0.90032	2.69494	1.74136
MagC	0.063450648					
MagC	0.062887865					
MagC	0.060689632	0.06234	0.00146	0.91363	1.25619	2.31090
C40-00	0.059438332					
C40-00	0.059044582					
C40-00	0.059951098	0.05948	0.00045	0.87165	5.79357	0.71997
C40-20(2pt)	0.062200182					
C40-20(2pt)	0.059466382					
C40-20(2pt)	0.058107265	0.05992	0.00208	0.87820	5.08620	3.30174
C40-40(2pt)	0.056268132					
C40-40(2pt)	0.054938265					
C40-40(2pt)	0.055297399	0.05550	0.00069	0.81337	12.09227	1.08967
C40-20(3pt)	0.057478732					
C40-20(3pt)	0.056418315					
C40-20(3pt)	0.057631999	0.05718	0.00066	0.83792	9.43913	1.04684

B4. Tukey's HSD and Confidence Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-20(3pt)-C40-40(2pt	0.0016751	-1.04E-03	0.004387	0.45197
C40-00-C40-40(2pt)	0.0039767	1.27E-03	0.006688	0.00176
C40-20(2pt)-C40-40(2pt	0.0044233	1.71E-03	0.007135	0.00054
Clay-C40-40(2pt)	0.0054282	2.72E-03	0.00814	4.1E-05
MagN-C40-40(2pt)	0.0059331	3.22E-03	0.008645	1.2E-05
MagC-C40-40(2pt)	0.0068414	4.13E-03	0.009553	1.5E-06
standard-C40-40(2pt)	0.0076346	5.29E-03	0.009983	0
C40-00-C40-20(3pt)	0.0023017	-4.10E-04	0.005013	0.13319
C40-20(2pt)-C40-20(3pt	0.0027483	3.67E-05	0.00546	0.0456
Clay-C40-20(3pt)	0.0037531	1.04E-03	0.006465	0.00322
MagN-C40-20(3pt)	0.004258	1.55E-03	0.00697	0.00083
MagC-C40-20(3pt)	0.0051664	2.45E-03	0.007878	7.8E-05
standard-C40-20(3pt)	0.0059595	3.61E-03	0.008308	1.3E-06
C40-20(2pt)-C40-00	0.0004466	-2.26E-03	0.003158	0.99902
Clay-C40-00	0.0014514	-1.26E-03	0.004163	0.61857
MagN-C40-00	0.0019563	-7.55E-04	0.004668	0.27552
MagC-C40-00	0.0028647	1.53E-04	0.005576	0.03392
standard-C40-00	0.0036578	1.31E-03	0.006006	0.00091
Clay-C40-20(2pt)	0.0010048	-1.71E-03	0.003716	0.90383
MagN-C40-20(2pt)	0.0015097	-1.20E-03	0.004221	0.5743
MagC-C40-20(2pt)	0.0024181	-2.93E-04	0.00513	0.1019
standard-C40-20(2pt)	0.0032112	8.63E-04	0.005559	0.00363
MagN-Clay	0.0005049	-2.21E-03	0.003216	0.99787
MagC-Clay	0.0014133	-1.30E-03	0.004125	0.64741
standard-Clay	0.0022064	-1.42E-04	0.004555	0.07484
MagC-MagN	0.0009084	-1.80E-03	0.00362	0.94029
standard-MagN	0.0017015	-6.47E-04	0.00405	0.2711
standard-MagC	0.0007931	-1.56E-03	0.003141	0.93786

	Clay	**MagN**	**MagC**	**C40-00**	**C40-20 (2pt)**	**C40-40 (2pt)**	**C40-20 (3pt)**
Clay		N.S.	N.S.	N.S.	<0.05	<0.05	<0.05
MagN	N.S.		N.S.	N.S.	N.S.	<0.05	<0.05
MagC	N.S.	N.S.		<0.05	N.S.	<0.05	<0.05
C40-00	N.S.	N.S.	<0.05		N.S.	<0.05	N.S.
C40-20(2pt)	N.S.	N.S.	N.S.	N.S.		<0.001	<0.05
C40-40(2pt)	<0.05	<0.05	<0.05	<0.05	<0.05		N.S.
C40-20(3pt)	<0.05	<0.05	<0.05	N.S.	<0.05	N.S.	

B4. Experimental data for Figure 10 (5 mg/L P) .

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error	
standard	0.34872						
standard	0.35054						
standard	0.34756						
standard	0.34989						
standard	0.32026						
standard	0.31894	0.33932	0.015314061	4.972730485			
Clay	0.34326						
Clay	0.34554						
Clay	0.34378	0.34420	0.001193541	5.044179063	-1.436807772	0.351745123	
MagN	0.34140						
MagN	0.34603						
MagN	0.35317	0.34686	0.005930408	5.083305632	-2.223630414	1.747734661	
MagC	0.34455						
MagC	0.33924						
MagC	0.34142	0.34174	0.002669019	5.00819363	-0.713152366	0.786579316	
C40-00	0.32025						
C40-00	0.31258						
C40-00	0.31858	0.31714	0.004033908	4.647678278	6.536694636	1.188822016	
C40-20(2pt)		0.33324					
C40-20(2pt)		0.32978					
C40-20(2pt)		0.33067	0.33123	0.001796304	4.854178784	2.384036321	0.529383814
C40-40(2pt)		0.32805					
C40-40(2pt)		0.32664					
C40-40(2pt)		0.33157	0.32875	0.002538869	4.817883398	3.113924787	0.748223376
C40-20(3pt)		0.33745					
C40-20(3pt)		0.34419					
C40-20(3pt)		0.36251	0.34805	0.012969016	5.100661304	-2.572647355	3.822063864

B4. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-40(2pt)-C40-00	0.011617	-0.00463	0.027868	0.251776
C40-20(2pt)-C40-00	0.014093	-0.00216	0.030344	0.109955
MagC-C40-00	0.0246	0.008349	0.040851	0.002107
Clay-C40-00	0.027057	0.010806	0.043308	0.000858
MagN-C40-00	0.02973	0.013479	0.045981	0.000334
C40-20(3pt)-C40-00	0.030913	0.014662	0.047164	0.000223
C40-20(2pt)-C40-40(2pt)	0.002477	-0.01377	0.018728	0.998046
MagC-C40-40(2pt)	0.012983	-0.00327	0.029234	0.161509
Clay-C40-40(2pt)	0.01544	-0.00081	0.031691	0.067563
MagN-C40-40(2pt)	0.018113	0.001862	0.034364	0.024711
C40-20(3pt)-C40-40(2pt)	0.019297	0.003046	0.035548	0.015715
MagC-C40-20(2pt)	0.010507	-0.00574	0.026758	0.349919
Clay-C40-20(2pt)	0.012963	-0.00329	0.029214	0.162603
MagN-C40-20(2pt)	0.015637	-0.00061	0.031888	0.062834
C40-20(3pt)-C40-20(2pt)	0.01682	0.000569	0.033071	0.040377
Clay-MagC	0.002457	-0.01379	0.018708	0.998131
MagN-MagC	0.00513	-0.01112	0.021381	0.924717
C40-20(3pt)-MagC	0.006313	-0.00994	0.022564	0.829057
MagN-Clay	0.002673	-0.01358	0.018924	0.997027
C40-20(3pt)-Clay	0.003857	-0.01239	0.020108	0.979861
C40-20(3pt)-MagN	0.001183	-0.01507	0.017434	0.999972

	Clay	MagN	MagC	C40-00	C40-20(2pt)	C40-40(2pt)	C40-20(3pt
Clay		N.S.	N.S.	<0.05	N.S.	N.S.	N.S.
MagN	N.S.		N.S.	<0.05	N.S.	<0.05	N.S.
MagC	N.S.	N.S.		<0.05	N.S.	N.S.	N.S.
C40-00	<0.05	<0.05	<0.05		<0.05	N.S.	<0.05
C40-20(2pt)	N.S.	N.S.	N.S.	<0.05		N.S.	<0.05
C40-40(2pt)	N.S.	<0.05	N.S.	N.S.	N.S.		<0.05
C40-20(3pt)	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05	

B5. Experimental data for Figure 11.

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error
standard	0.03106					
standard	0.03125					
standard	0.03093					
standard	0.03101					
standard	0.03120					
standard	0.03102	0.031079916	0.000123417	0.461661071		
Clay	0.02875					
Clay	0.02907					
Clay	0.03012	0.029312766	0.000717188	0.435411825	5.685826056	2.276645847
MagN	0.02894					
MagN	0.02938					
MagN	0.02875	0.029022999	0.000321072	0.431107631	6.618153738	1.019211804
MagC	0.02996					
MagC	0.02977					
MagC	0.02854	0.029422321	0.000770002	0.437039163	5.333329758	2.444299047
C40-00	0.02728					
C40-00	0.02785					
C40-00	0.02772	0.027614699	0.000296222	0.410188743	11.14937567	0.940329904
C40-20(2pt)		0.02786				
C40-20(2pt)		0.02730				
C40-20(2pt)		0.02695	0.027858666	0.001178959	0.413812624	10.36441003
	3.742494763					
C40-40(2pt)		0.02735				
C40-40(2pt)		0.02667				
C40-40(2pt)		0.02661	0.026893691	0.000338345	0.399478886	13.46922852
	1.074045871					
C40-20(3pt)		0.02895				
C40-20(3pt)		0.02966				
C40-20(3pt)		0.02938	0.029329166	0.00035806	0.435655431	5.633058862
	1.136626727					

B8. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
AC40-40(2pt)-C40-40(2pt)	0.005126	-2.37E-02	0.033964	0.999988
AC40-20(2pt)-C40-40(2pt)	0.012467	-1.64E-02	0.041305	0.93663
AC40-00-C40-40(2pt)	0.016094	-1.27E-02	0.044932	0.73009
C40-20(2pt)-C40-40(2pt)	0.032501	3.66E-03	0.061338	0.016731
C40-20(3pt)-C40-40(2pt)	0.033928	5.09E-03	0.062765	0.010714
C40-00-C40-40(2pt)	0.034884	6.05E-03	0.063722	0.007911
AMagN-C40-40(2pt)	0.037013	8.18E-03	0.065851	0.003985
AClay-C40-40(2pt)	0.041317	1.25E-02	0.070155	0.000968
AC40-20(3pt)-C40-40(2pt)	0.041561	1.27E-02	0.070398	0.000893
AMagC-C40-40(2pt)	0.042944	1.41E-02	0.071782	0.000564
MagC-C40-40(2pt)	0.049869	2.10E-02	0.078707	5.65E-05
MagN-C40-40(2pt)	0.050979	2.21E-02	0.079817	3.92E-05
Clay-C40-40(2pt)	0.059071	3.02E-02	0.087909	2.9E-06
AC40-20(2pt)-AC40-40(2pt)	0.007341	-2.15E-02	0.036178	0.999373
AC40-00-AC40-40(2pt)	0.010968	-1.79E-02	0.039805	0.975204
C40-20(2pt)-AC40-40(2pt)	0.027374	-1.46E-03	0.056212	0.075449
C40-20(3pt)-AC40-40(2pt)	0.028801	-3.65E-05	0.057639	0.050527
C40-00-AC40-40(2pt)	0.029758	9.20E-04	0.058595	0.038285
AMagN-AC40-40(2pt)	0.031887	3.05E-03	0.060724	0.020209
AClay-AC40-40(2pt)	0.036191	7.35E-03	0.065028	0.005202
AC40-20(3pt)-AC40-40(2pt)	0.036434	7.60E-03	0.065272	0.004808
AMagC-AC40-40(2pt)	0.037818	8.98E-03	0.066656	0.003066
MagC-AC40-40(2pt)	0.044743	1.59E-02	0.073581	0.00031
MagN-AC40-40(2pt)	0.045853	1.70E-02	0.07469	0.000214
Clay-AC40-40(2pt)	0.053945	2.51E-02	0.082783	1.49E-05
AC40-00-AC40-20(2pt)	0.003627	-2.52E-02	0.032465	1
C40-20(2pt)-AC40-20(2pt)	0.020034	-8.80E-03	0.048871	0.416251
C40-20(3pt)-AC40-20(2pt)	0.021461	-7.38E-03	0.050298	0.316642
C40-00-AC40-20(2pt)	0.022417	-6.42E-03	0.051255	0.25888
AMagN-AC40-20(2pt)	0.024546	-4.29E-03	0.053384	0.157895
AClay-AC40-20(2pt)	0.02885	1.22E-05	0.057688	0.049826
AC40-20(3pt)-AC40-20(2pt)	0.029094	2.56E-04	0.057931	0.04645
AMagC-AC40-20(2pt)	0.030477	1.64E-03	0.059315	0.030942
MagC-AC40-20(2pt)	0.037403	8.56E-03	0.06624	0.003511
MagN-AC40-20(2pt)	0.038512	9.67E-03	0.06735	0.002443
Clay-AC40-20(2pt)	0.046604	1.78E-02	0.075442	0.000167
C40-20(2pt)-AC40-00	0.016407	-1.24E-02	0.045244	0.706091
C40-20(3pt)-AC40-00	0.017834	-1.10E-02	0.046671	0.59125
C40-00-AC40-00	0.01879	-1.00E-02	0.047628	0.51328
AMagN-AC40-00	0.020919	-7.92E-03	0.049757	0.352676

AClay-AC40-00	0.025223	-3.61E-03	0.054061	0.133335
AC40-20(3pt)-AC40-00	0.025467	-3.37E-03	0.054304	0.125305
AMagC-AC40-00	0.02685	-1.99E-03	0.055688	0.087034
MagC-AC40-00	0.033776	4.94E-03	0.062613	0.01124
MagN-AC40-00	0.034885	6.05E-03	0.063723	0.007909
Clay-AC40-00	0.042977	1.41E-02	0.071815	0.000558
C40-20(3pt)-C40-20(2pt)	0.001427	-2.74E-02	0.030265	1
C40-00-C40-20(2pt)	0.002383	-2.65E-02	0.031221	1
AMagN-C40-20(2pt)	0.004512	-2.43E-02	0.03335	0.999997
AClay-C40-20(2pt)	0.008816	-2.00E-02	0.037654	0.996208
AC40-20(3pt)-C40-20(2pt)	0.00906	-1.98E-02	0.037898	0.995123
AMagC-C40-20(2pt)	0.010444	-1.84E-02	0.039282	0.983249
MagC-C40-20(2pt)	0.017369	-1.15E-02	0.046207	0.629248
MagN-C40-20(2pt)	0.018478	-1.04E-02	0.047316	0.538524
Clay-C40-20(2pt)	0.026571	-2.27E-03	0.055409	0.093827
C40-00-C40-20(3pt)	0.000956	-2.79E-02	0.029794	1
AMagN-C40-20(3pt)	0.003085	-2.58E-02	0.031923	1
AClay-C40-20(3pt)	0.007389	-2.14E-02	0.036227	0.999329
AC40-20(3pt)-C40-20(3pt)	0.007633	-2.12E-02	0.036471	0.999066
AMagC-C40-20(3pt)	0.009017	-1.98E-02	0.037855	0.995333
MagC-C40-20(3pt)	0.015942	-1.29E-02	0.04478	0.741517
MagN-C40-20(3pt)	0.017051	-1.18E-02	0.045889	0.654983
Clay-C40-20(3pt)	0.025144	-3.69E-03	0.053982	0.136033
AMagN-C40-00	0.002129	-2.67E-02	0.030967	1
AClay-C40-00	0.006433	-2.24E-02	0.035271	0.999845
AC40-20(3pt)-C40-00	0.006677	-2.22E-02	0.035515	0.999768
AMagC-C40-00	0.00806	-2.08E-02	0.036898	0.998392
MagC-C40-00	0.014986	-1.39E-02	0.043823	0.808951
MagN-C40-00	0.016095	-1.27E-02	0.044933	0.730003
Clay-C40-00	0.024188	-4.65E-03	0.053025	0.172302
AClay-AMagN	0.004304	-2.45E-02	0.033142	0.999999
AC40-20(3pt)-AMagN	0.004548	-2.43E-02	0.033385	0.999997
AMagC-AMagN	0.005931	-2.29E-02	0.034769	0.999936
MagC-AMagN	0.012857	-1.60E-02	0.041694	0.922193
MagN-AMagN	0.013966	-1.49E-02	0.042804	0.870264
Clay-AMagN	0.022058	-6.78E-03	0.050896	0.279629
AC40-20(3pt)-AClay	0.000244	-2.86E-02	0.029081	1
AMagC-AClay	0.001627	-2.72E-02	0.030465	1
MagC-AClay	0.008553	-2.03E-02	0.03739	0.997151
MagN-AClay	0.009662	-1.92E-02	0.0385	0.991331
Clay-AClay	0.017754	-1.11E-02	0.046592	0.597735
AMagC-AC40-20(3pt)	0.001384	-2.75E-02	0.030221	1
MagC-AC40-20(3pt)	0.008309	-2.05E-02	0.037147	0.99784
MagN-AC40-20(3pt)	0.009418	-1.94E-02	0.038256	0.993079
Clay-AC40-20(3pt)	0.017511	-1.13E-02	0.046349	0.61767
MagC-AMagC	0.006925	-2.19E-02	0.035763	0.999658
MagN-AMagC	0.008035	-2.08E-02	0.036872	0.998442
Clay-AMagC	0.016127	-1.27E-02	0.044965	0.727569
MagN-MagC	0.001109	-2.77E-02	0.029947	1
Clay-MagC	0.009202	-1.96E-02	0.03804	0.994382
Clay-MagN	0.008093	-2.07E-02	0.03693	0.998329

	AClay	AMagN	AMagC	AC40-00	AC40-20(2pt)	AC40-40(2pt)	AC40-20(3pt)	Clay	MagN	MagC	C40-00	C40-20(2pt)	C40-40(2pt)	C40-20(3pt)
AClay		N.D.	N.D.	N.D.	<0.05	<0.05	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.
AMagN	N.D.		N.D.	N.D.	N.D.	<0.05	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.
AMagC	N.D.	N.D.		N.D.	<0.05	<0.05	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.
AC40-00	N.D.	N.D.	N.D.		N.D.	N.D.	N.D.	<0.05	<0.05	<0.05	N.D.	N.D.	N.D.	N.D.
AC40-20(2pt)	<0.05	N.D.	<0.05	N.D.		N.D.	<0.05	<0.05	<0.05	<0.05	N.D.	N.D.	N.D.	N.D.
AC40-40(2pt)	<0.05	<0.05	<0.05	N.D.	N.D.		<0.05	<0.05	<0.05	<0.05	<0.05	N.D.	N.D.	N.D.
AC40-20(3pt)	N.D.	N.D.	N.D.	N.D.	<0.05	<0.05		N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.
Clay	N.D.	N.D.	N.D.	<0.05	<0.05	<0.05	N.D.		N.D.	N.D.	N.D.	N.D.	<0.05	N.D.
MagN	N.D.	N.D.	N.D.	<0.05	<0.05	<0.05	N.D.	N.D.		N.D.	N.D.	N.D.	<0.05	N.D.
MagC	N.D.	N.D.	N.D.	<0.05	<0.05	<0.05	N.D.	N.D.	N.D.		N.D.	N.D.	<0.05	N.D.
C40-00	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.	N.D.	N.D.	N.D.		N.D.	<0.05	N.D.
C40-20(2pt)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.		<0.05	N.D.
C40-40(2pt)	<0.05	<0.05	<0.05	N.D.	N.D.	N.D.	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05
C40-20(3pt)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	

B5. Experimental data for Figure 12.

Polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error
std	0.03039					
std	0.02982					
std	0.02943					
std	0.02928					
std	0.03052					
std	0.03058	0.030004258	0.000573521	0.439712395		
C40-002HR	0.02650					
C40-002HR	0.02704					
C40-002HR	0.02613	0.02655	0.000457468	0.389153012	11.49828455	1.524676213
C40-20(2pt)2HR	0.02774					
C40-20(2pt)2HR	0.02583					
C40-20(2pt)2HR	0.02501	0.02619	0.001398501	0.38385352	12.70350236	4.661007764
C40-20(3pt)2HR	0.02879					
C40-20(3pt)2HR	0.02764					
C40-20(3pt)2HR	0.02749	0.02797	0.000710678	0.409920124	6.775399381	2.368591317
C40-0012HR	0.02368					
C40-0012HR	0.02364					
C40-0012HR	0.02464	0.02399	0.000567668	0.351539002	20.05251477	1.891957503
C40-20(2pt)12HR	0.02598					
C40-20(2pt)12HR	0.02607					
C40-20(2pt)12HR	0.02566	0.02590	0.000219319	0.379621319	13.66599537	0.730960879
C40-20(3pt)12HR	0.02659					
C40-20(3pt)12HR	0.02693					
C40-20(3pt)12HR	0.02641	0.02665	0.000263534	0.390497446	11.19253165	0.878322003
C40-0024HR	0.02325					
C40-0024HR	0.02521					
C40-0024HR	0.02480	0.02442	0.001032098	0.357841873	18.61910712	3.439839433
C40-20(2pt)24HR	0.02705					
C40-20(2pt)24HR	0.02728					
C40-20(2pt)24HR	0.02616	0.02683	0.00059397	0.39320056	10.57778558	1.979617876
C40-20(3pt)24HR	0.02761					
C40-20(3pt)24HR	0.02983					
C40-20(3pt)24HR	0.02796	0.02847	0.001192114	0.417181513	5.124004158	3.973148167

B5. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-0024HR-C40-0012HR	0.006303	-3.14E-02	0.0439823	0.9999647
C40-20(2pt)12HR-C40-0012HR	0.028082333	-9.60E-03	0.0657616	0.2897453
C40-20(2pt)2HR-C40-0012HR	0.032314333	-5.36E-03	0.0699936	0.1422208
C40-002HR-C40-0012HR	0.037614333	-6.50E-05	0.0752936	0.0506737
C40-20(3pt)12HR-C40-0012HR	0.038958333	1.28E-03	0.0766376	0.0383068
C40-20(2pt)24HR-C40-0012HR	0.04166156	3.98E-03	0.0793409	0.0214689
C40-20(3pt)2HR-C40-0012HR	0.058381	2.07E-02	0.0960603	0.0004768
C40-20(3pt)24HR-C40-0012HR	0.065642513	2.80E-02	0.1033218	0.0000904
C40-20(2pt)20MIN-C40-0012HR	0.069341191	3.17E-02	0.1070205	0.0000393
C40-20(3pt)20MIN-C40-0012HR	0.070749048	3.31E-02	0.1084284	0.0000287
C40-0020MIN-C40-0012HR	0.071692504	3.40E-02	0.1093718	0.0000233
C40-20(2pt)12HR-C40-0024HR	0.021779333	-1.59E-02	0.0594586	0.6373633
C40-20(2pt)2HR-C40-0024HR	0.026011333	-1.17E-02	0.0636906	0.3909586
C40-002HR-C40-0024HR	0.031311333	-6.37E-03	0.0689906	0.1701422
C40-20(3pt)12HR-C40-0024HR	0.032655333	-5.02E-03	0.0703346	0.1336346
C40-20(2pt)24HR-C40-0024HR	0.03535856	-2.32E-03	0.0730379	0.0798462
C40-20(3pt)2HR-C40-0024HR	0.052078	1.44E-02	0.0897573	0.0020436
C40-20(3pt)24HR-C40-0024HR	0.059339513	2.17E-02	0.0970188	0.0003822
C40-20(2pt)20MIN-C40-0024HR	0.063038191	2.54E-02	0.1007175	0.0001636
C40-20(3pt)20MIN-C40-0024HR	0.064446048	2.68E-02	0.1021254	0.0001186
C40-0020MIN-C40-0024HR	0.065389504	2.77E-02	0.1030688	0.0000957
C40-20(2pt)2HR-C40-20(2pt)12HR	0.004232	-3.34E-02	0.0419113	0.9999994
C40-002HR-C40-20(2pt)12HR	0.009532	-2.81E-02	0.0472113	0.9982694
C40-20(3pt)12HR-C40-20(2pt)12HR	0.010876	-2.68E-02	0.0485553	0.9947032
C40-20(2pt)24HR-C40-20(2pt)12HR	0.013579227	-2.41E-02	0.0512585	0.9712531
C40-20(3pt)2HR-C40-20(2pt)12HR	0.030298667	-7.38E-03	0.067978	0.2026164
C40-20(3pt)24HR-C40-20(2pt)12HR	0.03756018	-1.19E-04	0.0752395	0.0512416
C40-20(2pt)20MIN-C40-20(2pt)12HR	0.041258857	3.58E-03	0.0789382	0.0234313
C40-20(3pt)20MIN-C40-20(2pt)12HR	0.042666715	4.99E-03	0.080346	0.0172302
C40-0020MIN-C40-20(2pt)12HR	0.043610171	5.93E-03	0.0812895	0.0139896
C40-002HR-C40-20(2pt)2HR	0.0053	-3.24E-02	0.0429793	0.9999939
C40-20(3pt)12HR-C40-20(2pt)2HR	0.006644	-3.10E-02	0.0443233	0.9999406
C40-20(2pt)24HR-C40-20(2pt)2HR	0.009347227	-2.83E-02	0.0470265	0.998543
C40-20(3pt)2HR-C40-20(2pt)2HR	0.026066667	-1.16E-02	0.063746	0.3880265
C40-20(3pt)24HR-C40-20(2pt)2HR	0.03332818	-4.35E-03	0.0710075	0.1179624
C40-20(2pt)20MIN-C40-20(2pt)2HR	0.037026857	-6.52E-04	0.0747062	0.0571531
C40-20(3pt)20MIN-C40-20(2pt)2HR	0.038434715	7.55E-04	0.076114	0.0427488
C40-0020MIN-C40-20(2pt)2HR	0.039378171	1.70E-03	0.0770575	0.0350593
C40-20(3pt)12HR-C40-002HR	0.001344	-3.63E-02	0.0390233	1
C40-20(2pt)24HR-C40-002HR	0.004047227	-3.36E-02	0.0417265	0.9999996
C40-20(3pt)2HR-C40-002HR	0.020766667	-1.69E-02	0.058446	0.6970782
C40-20(3pt)24HR-C40-002HR	0.02802818	-9.65E-03	0.0657075	0.292155
C40-20(2pt)20MIN-C40-002HR	0.031726857	-5.95E-03	0.0694062	0.1580796
C40-20(3pt)20MIN-C40-002HR	0.033134715	-4.54E-03	0.070814	0.1223006
C40-0020MIN-C40-002HR	0.034078171	-3.60E-03	0.0717575	0.1023637
C40-20(2pt)24HR-C40-20(3pt)12HR	0.002703227	-3.50E-02	0.0403825	1
C40-20(3pt)2HR-C40-20(3pt)12HR	0.019422667	-1.83E-02	0.057102	0.771655

C40-20(3pt)24HR-C40-20(3pt)12HR	0.02668418	-1.10E-02	0.0643635	0.3561081
C40-20(2pt)20MIN-C40-20(3pt)12HR	0.030382857	-7.30E-03	0.0680622	0.1997458
C40-20(3pt)20MIN-C40-20(3pt)12HR	0.031790715	-5.89E-03	0.06947	0.1562888
C40-0020MIN-C40-20(3pt)12HR	0.032734171	-4.95E-03	0.0704135	0.1317123
C40-20(3pt)2HR-C40-20(2pt)24HR	0.01671944	-2.10E-02	0.0543988	0.8928964
C40-20(3pt)24HR-C40-20(2pt)24HR	0.023980953	-1.37E-02	0.0616603	0.5053448
C40-20(2pt)20MIN-C40-20(2pt)24HR	0.02767963	-1.00E-02	0.0653589	0.30798
C40-20(3pt)20MIN-C40-20(2pt)24HR	0.029087488	-8.59E-03	0.0667668	0.2474486
C40-0020MIN-C40-20(2pt)24HR	0.030030944	-7.65E-03	0.0677103	0.2119548
C40-20(3pt)24HR-C40-20(3pt)2HR	0.007261513	-3.04E-02	0.0449408	0.999859
C40-20(2pt)20MIN-C40-20(3pt)2HR	0.010960191	-2.67E-02	0.0486395	0.9943587
C40-20(3pt)20MIN-C40-20(3pt)2HR	0.012368048	-2.53E-02	0.0500474	0.9854272
C40-0020MIN-C40-20(3pt)2HR	0.013311504	-2.44E-02	0.0509908	0.9750219
C40-20(2pt)20MIN-C40-20(3pt)24HR	0.003698677	-3.40E-02	0.041378	0.9999999
C40-20(3pt)20MIN-C40-20(3pt)24HR	0.005106535	-3.26E-02	0.0427858	0.9999958
C40-0020MIN-C40-20(3pt)24HR	0.006049991	-3.16E-02	0.0437293	0.9999766
C40-20(3pt)20MIN-C40-20(2pt)20MIN	0.001407857	-3.63E-02	0.0390872	1
C40-0020MIN-C40-20(2pt)20MIN	0.002351313	-3.53E-02	0.0400306	1
C40-0020MIN-C40-20(3pt)20MIN	0.000943456	-3.67E-02	0.0386228	1

	C40-0020MIN	C40-20(2pt)2	C40-20(3pt)2	C40-002HR	C40-20(2pt)2HR	C40-20(3pt)2HR	C40-0012HR	C40-20(2pt)12HR	C40-20(3pt)12HR	C40-0024HR	C40-20(2pt)24HR	C40-20(3pt
C40-0020MIN		N.D.	N.D.	N.D.	<0.05	N.D.	<0.05	<0.05	N.D.	<0.05	N.D.	N.D.
C40-20(2pt)20MIN	N.D.		N.D.	N.D.	N.D.	N.D.	<0.05	<0.05	N.D.	<0.05	N.D.	N.D.
C40-20(3pt)20MIN	N.D.	N.D.		N.D.	<0.05	N.D.	<0.05	<0.05	N.D.	<0.05	N.D.	N.D.
C40-002HR	N.D.	N.D.	N.D.		N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
C40-20(2pt)2HR	<0.05	N.D.	<0.05	N.D.		N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
C40-20(3pt)2HR	N.D.	N.D.	N.D.	N.D.	N.D.		<0.05	N.D.	N.D.	<0.05	N.D.	N.D.
C40-0012HR	<0.05	<0.05	<0.05	N.D.	N.D.	<0.05		N.D.	<0.05	N.D.	<0.05	<0.05
C40-20(2pt)12HR	<0.05	<0.05	<0.05	N.D.	N.D.	N.D.	N.D.		N.D.	N.D.	N.D.	N.D.
C40-20(3pt)12HR	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.		N.D.	N.D.	N.D.
C40-0024HR	<0.05	<0.05	<0.05	N.D.	N.D.	<0.05	N.D.	N.D.	N.D.		N.D.	<0.05
C40-20(2pt)24HR	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.	N.D.	N.D.		N.D.
C40-20(3pt)24HR	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	<0.05	N.D.	N.D.	<0.05	N.D.	

B6. Experimental data for Figure 13.

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error	
standard	0.063						
standard	0.064						
standard	0.064						
standard	0.064						
standard	0.065						
standard	0.064	0.064014023	0.000589907	0.8750717			
Clay	0.053						
Clay	0.054						
Clay	0.059	0.055668876	0.003356255	0.76099354	13.03643572	5.24299918	
Mag C	0.041						
Mag C	0.040						
Mag C	0.040	0.040248221	0.000592479	0.550193184	37.12593104	0.925545924	
C40-00	0.032						
C40-01	0.034						
C40-02	0.033	0.033019777	0.001116764	0.451380351	48.41790096	1.744562096	
C40-20 (2pt)		0.043					
C40-20 (2pt)		0.042					
C40-20 (2pt)		0.047	0.043981921	0.002691944	0.601232867	31.29330239	4.205240639
C40-40 (2pt)		0.043					
C40-40 (2pt)		0.041					
C40-40 (2pt)		0.040	0.041537971	0.001262799	0.567824066	35.11113819	1.972691941
C40-20 (3pt)		0.046					
C40-20 (3pt)		0.048					
C40-20 (3pt)		0.046	0.046638677	0.001161109	0.637550709	27.14303189	1.813835823

B6. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
MagC(100ppm)-C40-00(100PPM)	0.09881	0.042207	0.1554191	0.00017
C40-40(2pt)(100PPM)-C40-00(100PPM)	0.11644	0.059837	0.17305	1.75E-05
C40-20(2pt)(100PPM)-C40-00(100PPM)	0.14985	0.093246	0.2064588	4E-07
C40-20(3pt)(100PPM)-C40-00(100PPM)	0.18617	0.129564	0.2427767	0
C40-40(2pt)(25PPM)-C40-00(100PPM)	0.36199	0.305384	0.418597	0
C40-20(3pt)(25PPM)-C40-00(100PPM)	0.38654	0.329933	0.4431453	0
C40-00(25PPM)-C40-00(100PPM)	0.42027	0.363664	0.4768761	0
C40-20(2pt)(25PPM)-C40-00(100PPM)	0.42681	0.370209	0.4834211	0
MagC(25PPM)-C40-00(100PPM)	0.46225	0.405646	0.5188584	0
C40-40(2pt)(100PPM)-MagC(100ppm)	0.01763	-0.03898	0.0742372	0.978664
C40-20(2pt)(100PPM)-MagC(100ppm)	0.05104	-0.00557	0.107646	0.099223
C40-20(3pt)(100PPM)-MagC(100ppm)	0.08736	0.030751	0.1439638	0.000791
C40-40(2pt)(25PPM)-MagC(100ppm)	0.26318	0.206572	0.3197842	0
C40-20(3pt)(25PPM)-MagC(100ppm)	0.28773	0.23112	0.3443325	0
C40-00(25PPM)-MagC(100ppm)	0.32146	0.264851	0.3780633	0
C40-20(2pt)(25PPM)-MagC(100ppm)	0.328	0.271396	0.3846083	0
MagC(25PPM)-MagC(100ppm)	0.36344	0.306833	0.4200456	0
C40-20(2pt)(100PPM)-C40-40(2pt)(100PPM	0.03341	-0.0232	0.0900151	0.55333
C40-20(3pt)(100PPM)-C40-40(2pt)(100PPM	0.06973	0.01312	0.1263329	0.008816
C40-40(2pt)(25PPM)-C40-40(2pt)(100PPM)	0.24555	0.188941	0.3021533	0
C40-20(3pt)(25PPM)-C40-40(2pt)(100PPM)	0.2701	0.213489	0.3267016	0
C40-00(25PPM)-C40-40(2pt)(100PPM)	0.30383	0.24722	0.3604324	0
C40-20(2pt)(25PPM)-C40-40(2pt)(100PPM)	0.31037	0.253765	0.3669774	0
MagC(25PPM)-C40-40(2pt)(100PPM)	0.34581	0.289202	0.4024147	0
C40-20(3pt)(100PPM)-C40-20(2pt)(100PPM	0.03632	-0.02029	0.0929241	0.445329
C40-40(2pt)(25PPM)-C40-20(2pt)(100PPM)	0.21214	0.155532	0.2687445	0
C40-20(3pt)(25PPM)-C40-20(2pt)(100PPM)	0.23669	0.18008	0.2932928	0
C40-00(25PPM)-C40-20(2pt)(100PPM)	0.27042	0.213811	0.3270236	0
C40-20(2pt)(25PPM)-C40-20(2pt)(100PPM)	0.27696	0.220356	0.3335686	0
MagC(25PPM)-C40-20(2pt)(100PPM)	0.3124	0.255793	0.3690059	0
C40-40(2pt)(25PPM)-C40-20(3pt)(100PPM)	0.17582	0.119214	0.2324266	0
C40-20(3pt)(25PPM)-C40-20(3pt)(100PPM)	0.20037	0.143762	0.256975	0
C40-00(25PPM)-C40-20(3pt)(100PPM)	0.2341	0.177493	0.2907057	0
C40-20(2pt)(25PPM)-C40-20(3pt)(100PPM)	0.24064	0.184038	0.2972507	0
MagC(25PPM)-C40-20(3pt)(100PPM)	0.27608	0.219475	0.3326881	0
C40-20(3pt)(25PPM)-C40-40(2pt)(25PPM)	0.02455	-0.03206	0.0811546	0.862291
C40-00(25PPM)-C40-40(2pt)(25PPM)	0.05828	0.001673	0.1148854	0.04038
C40-20(2pt)(25PPM)-C40-40(2pt)(25PPM)	0.06482	0.008218	0.1214304	0.017083
MagC(25PPM)-C40-40(2pt)(25PPM)	0.10026	0.043655	0.1568677	0.00014
C40-00(25PPM)-C40-20(3pt)(25PPM)	0.03373	-0.02288	0.0903371	0.54107
C40-20(2pt)(25PPM)-C40-20(3pt)(25PPM)	0.04028	-0.01633	0.0968821	0.315555
MagC(25PPM)-C40-20(3pt)(25PPM)	0.07571	0.019107	0.1323194	0.003892
C40-20(2pt)(25PPM)-C40-00(25PPM)	0.00655	-0.05006	0.0631513	0.99999
MagC(25PPM)-C40-00(25PPM)	0.04198	-0.01462	0.0985886	0.267824
MagC(25PPM)-C40-20(2pt)(25PPM)	0.03544	-0.02117	0.0920436	0.477211

	MagC(100ppm)	C40-00(100PPM)	C40-20(2pt)(100PPM)	C40-40(2pt)(100PPM)	C40-20(3pt)(100PPM)	MagC(25PPM)	C40-00(25PPM)	C40-20(2pt)(25PPM)	C40-40(2pt)(25PPM)	C40-20(3pt)(25PPM)
MagC(100ppm)		<0.05	N.A.	N.A.	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C40-00(100PPM)	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C40-20(2pt)(100PPM)	N.A.	<0.05		N.A.	N.A.	<0.05	<0.05	<0.05	<0.05	<0.05
C40-40(2pt)(100PPM)	N.A.	<0.05	N.A.		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C40-20(3pt)(100PPM)	<0.05	<0.05	N.A.	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05
MagC(25PPM)	<0.05	<0.05	<0.05	<0.05	<0.05		N.A.	N.A.	<0.05	<0.05
C40-00(25PPM)	<0.05	<0.05	<0.05	<0.05	<0.05	N.A.		N.A.	<0.05	N.A.
C40-20(2pt)(25PPM)	<0.05	<0.05	<0.05	<0.05	<0.05	N.A.	N.A.		N.A.	N.A.
C40-40(2pt)(25PPM)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		N.A.
C40-20(3pt)(25PPM)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.A.	N.A.	<0.05	

B7. Experimental data for Figure 14.

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error	
standard	0.057338						
standard	0.057508						
standard	0.059433						
standard	0.059238						
standard	0.058388						
standard	0.058029	0.058322457	0.000870849	0.848241813			
Clay 1ppmpo4		0.009374					
Clay 1ppmpo4		0.008139					
Clay 1ppmpo4		0.007850	0.0084547	0.000809458	0.121122029	85.72081365	1.38790181
C40-00	0.007876						
C40-00	0.008210						
C40-00	0.008224	0.008103266	0.000197228	0.116087395	86.31435121	0.338168387	
C40-40	0.005908						
C40-40	0.006756						
C40-40	0.006174	0.006279417	0.00043356	0.089958921	89.39466087	0.74338452	
std 5ppm po4		0.327515					
std 5ppm po4		0.342305					
std 5ppm po4		0.336032	0.33528413	0.007423227	4.803280452		
Clay 1ppmpo4		0.162227					
Clay 1ppmpo4		0.163266					
Clay 1ppmpo4		0.152888	0.15946019	0.005715194	2.284426688	52.44028096	1.730521169
C40-00	0.129676						
C40-00	0.126451						
C40-00	0.130131	0.128752602	0.002006527	1.844509781	61.59895724	0.607562592	
C40-40	0.124536						
C40-40	0.122440						
C40-40	0.121740	0.12290563	0.001455117	1.760746059	63.34284296	0.440599244	

B7. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

1ppm PO4				
	diff	lwr	upr	p adj
C40-001ppm(K)-C40-401ppm(K)	0.0261285	0.005432	0.046825	0.011312
Clay1ppm(K)-C40-401ppm(K)	0.0311631	0.010467	0.051859	0.002948
C40-401ppm(S)-C40-401ppm(K)	0.7234121	0.702716	0.744108	0
C40-001ppm(S)-C40-401ppm(K)	0.7816912	0.760995	0.802387	0
Clay1ppm(S)-C40-401ppm(K)	0.8029619	0.782266	0.823658	0
Clay1ppm(K)-C40-001ppm(K)	0.0050346	-0.01566	0.025731	0.958673
C40-401ppm(S)-C40-001ppm(K)	0.6972836	0.676587	0.71798	0
C40-001ppm(S)-C40-001ppm(K)	0.7555628	0.734867	0.776259	0
Clay1ppm(S)-C40-001ppm(K)	0.7768334	0.756137	0.79753	0
C40-401ppm(S)-Clay1ppm(K)	0.692249	0.671553	0.712945	0
C40-001ppm(S)-Clay1ppm(K)	0.7505281	0.729832	0.771224	0
Clay1ppm(S)-Clay1ppm(K)	0.7717988	0.751103	0.792495	0
C40-001ppm(S)-C40-401ppm(S)	0.0582791	0.037583	0.078975	7.6E-06
Clay1ppm(S)-C40-401ppm(S)	0.0795498	0.058854	0.100246	3E-07
Clay1ppm(S)-C40-001ppm(S)	0.0212707	0.000574	0.041967	0.042759

	Clay1ppm(K)	**C40-001ppm(K)**	**C40-401ppm(K)**
Clay1ppm(K)		N.S.	<0.05
C40-001ppm(K)	N.S.		<0.05
C40-401ppm(K)	<0.05	<0.05	

5ppm PO4				
	diff	lwr	upr	p adj
C40-005ppm(K)-C40-405ppm(K)	0.08376372	-0.04462756	0.212155	0.3083882
Clay5ppm(K)-C40-405ppm(K)	0.52368063	0.39528934	0.6520719	0.0000001
C40-005ppm(S)-C40-405ppm(K)	2.88693222	2.75854093	3.0153235	0
C40-405ppm(S)-C40-405ppm(K)	3.05713734	2.92874605	3.1855286	0
Clay5ppm(S)-C40-405ppm(K)	3.283433	3.15504172	3.4118243	0
Clay5ppm(K)-C40-005ppm(K)	0.43991691	0.31152562	0.5683082	0.0000009
C40-005ppm(S)-C40-005ppm(K)	2.8031685	2.67477721	2.9315598	0
C40-405ppm(S)-C40-005ppm(K)	2.97337362	2.84498233	3.1017649	0
Clay5ppm(S)-C40-005ppm(K)	3.19966928	3.071278	3.3280606	0
C40-005ppm(S)-Clay5ppm(K)	2.36325159	2.23486031	2.4916429	0
C40-405ppm(S)-Clay5ppm(K)	2.53345671	2.40506542	2.661848	0
Clay5ppm(S)-Clay5ppm(K)	2.75975238	2.63136109	2.8881437	0
C40-405ppm(S)-C40-005ppm(S)	0.17020512	0.04181383	0.2985964	0.0079348
Clay5ppm(S)-C40-005ppm(S)	0.39650078	0.2681095	0.5248921	0.0000028
Clay5ppm(S)-C40-405ppm(S)	0.22629567	0.09790438	0.354687	0.0007683

	Clay1ppm(K)	**C40-001ppm(K)**	**C40-401ppm(K)**
Clay1ppm(K)		<0.05	<0.05
C40-001ppm(K)	<0.05		N.S.
C40-401ppm(K)	<0.05	N.S.	

B8. Experimental data for Figure 15.

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error
standard	0.345					
standard	0.344					
standard	0.347					
standard	0.348					
standard	0.352					
standard	0.335	0.34504938	0.005589306	5.018398185		
Clay(250mg)	0.242					
Clay(250mg)	0.242					
Clay(250mg)	0.225	0.236592294	0.01005444	3.389421204	32.46009824	2.91391347
C40-00(250mg)		0.200				
C40-00(250mg)		0.191				
C40-00(250mg)		0.188	0.19289494	0.006384758	2.763412904	44.93436347
	1.850389582					
C40-40(250mg)		0.140				
C40-40(250mg)		0.129				
C40-40(250mg)		0.136	0.135120591	0.005968783	1.935737587	61.42718223
	1.729834476					
Clay(100mg)	0.256					
Clay(100mg)	0.287					
Clay(100mg)	0.286	0.276508126	0.017348862	3.961255418	21.06534253	5.027935978
C40-00(100mg)		0.239				
C40-00(100mg)		0.247				
C40-00(100mg)		0.242	0.242794555	0.004024499	3.478274795	30.68954144
	1.166354538					
C40-40(100mg)		0.166				
C40-40(100mg)		0.146				
C40-40(100mg)		0.154	0.155405374	0.010073954	2.226337386	55.63649388
	2.919568742					

B8. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-00(500mg)-C40-40(500mg)	0.085	-0.25954	0.429613	0.9923405
C40-40(250mg)-C40-40(500mg)	0.148	-0.19638	0.492772	0.8385231
C40-40(100mg)-C40-40(500mg)	0.439	0.094224	0.783372	0.0071486
Clay(500mg)-C40-40(500mg)	0.532	0.187075	0.876224	0.001017
C40-00(250mg)-C40-40(500mg)	0.976	0.631299	1.320448	0.0000003
Clay(250mg)-C40-40(500mg)	1.602	1.257307	1.946456	0
C40-00(100mg)-C40-40(500mg)	1.691	1.346161	2.03531	0
Clay(100mg)-C40-40(500mg)	2.174	1.829142	2.51829	0
C40-40(250mg)-C40-00(500mg)	0.063	-0.28141	0.407734	0.9989882
C40-40(100mg)-C40-00(500mg)	0.354	0.009185	0.698334	0.0416165
Clay(500mg)-C40-00(500mg)	0.447	0.102037	0.791186	0.0060634
C40-00(250mg)-C40-00(500mg)	0.891	0.546261	1.235409	0.0000012
Clay(250mg)-C40-00(500mg)	1.517	1.172269	1.861418	0
C40-00(100mg)-C40-00(500mg)	1.606	1.261123	1.950271	0
Clay(100mg)-C40-00(500mg)	2.089	1.744103	2.433252	0
C40-40(100mg)-C40-40(250mg)	0.291	-0.05397	0.635174	0.139392
Clay(500mg)-C40-40(250mg)	0.383	0.038877	0.728026	0.0227246
C40-00(250mg)-C40-40(250mg)	0.828	0.483101	1.17225	0.0000035
Clay(250mg)-C40-40(250mg)	1.454	1.109109	1.798258	0
C40-00(100mg)-C40-40(250mg)	1.543	1.197963	1.887112	0
Clay(100mg)-C40-40(250mg)	2.026	1.680943	2.370092	0
Clay(500mg)-C40-40(100mg)	0.093	-0.25172	0.437426	0.9866308
C40-00(250mg)-C40-40(100mg)	0.537	0.192501	0.88165	0.0009086
Clay(250mg)-C40-40(100mg)	1.163	0.818509	1.507658	0
C40-00(100mg)-C40-40(100mg)	1.252	0.907363	1.596512	0
Clay(100mg)-C40-40(100mg)	1.735	1.390344	2.079492	0
C40-00(250mg)-Clay(500mg)	0.444	0.09965	0.788798	0.0063763
Clay(250mg)-Clay(500mg)	1.07	0.725658	1.414807	0.0000001
C40-00(100mg)-Clay(500mg)	1.159	0.814511	1.50366	0
Clay(100mg)-Clay(500mg)	1.642	1.297492	1.986641	0
Clay(250mg)-C40-00(250mg)	0.626	0.281434	0.970583	0.000149
C40-00(100mg)-C40-00(250mg)	0.715	0.370288	1.059436	0.0000267
Clay(100mg)-C40-00(250mg)	1.198	0.853268	1.542417	0
C40-00(100mg)-Clay(250mg)	0.089	-0.25572	0.433428	0.9898565
Clay(100mg)-Clay(250mg)	0.572	0.22726	0.916409	0.0004441
Clay(100mg)-C40-00(100mg)	0.483	0.138406	0.827555	0.002817

	Clay(500mg)	C40-00(500mg)	C40-40(500mg	Clay(250mg)	C40-00(250mg)	C40-40(250mg)	Clay(100mg)	C40-00(100mg)	C40-40(100mg)
Clay(500mg)		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.
C40-00(500mg)	<0.05		N.S.	<0.05	<0.05	N.S.	<0.05	<0.05	<0.05
C40-40(500mg)	<0.05	N.S.		<0.05	<0.05	N.S.	<0.05	<0.05	<0.05
Clay(250mg)	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	N.S.	<0.05
C40-00(250mg)	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
C40-40(250mg)	<0.05	N.S.	N.S.	<0.05	<0.05		<0.05	<0.05	N.S.
Clay(100mg)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05
C40-00(100mg)	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05	<0.05		<0.05
C40-40(100mg)	N.S.	<0.05	<0.05	<0.05	<0.05	N.S.	<0.05	<0.05	

B9. Experimental data for Figure 16.

polymer	Area	Average	Std Dev	Po4 Conc	% removed	% error	
standard	0.271						
standard	0.332						
standard	0.275						
standard	0.273						
standard	0.265						
standard	0.266	0.280038857	0.025526752	4.103689408			
Clay	0.185						
Clay	0.190						
Clay	0.181	0.185656779	0.004509276	2.720614434	33.70320792	1.610232179	
MagC	0.196						
MagC	0.204						
MagC	0.197	0.199186501	0.00429922	2.918878979	28.87183486	1.535222624	
C40-00	0.196						
C40-00	0.204						
C40-00	0.194	0.198184762	0.005486907	2.904199497	29.2295491	1.95933761	
C40-20 (2pt)		0.182					
C40-20 (2pt)		0.180					
C40-20 (2pt)		0.174	0.178850629	0.004541036	2.620877115	36.13363844	1.621573384
C40-40 (2pt)		0.190					
C40-40 (2pt)		0.189					
C40-40 (2pt)		0.190	0.189595173	0.00057315	2.778327665	32.29683368	0.204668136
C40-20 (3pt)		0.162					
C40-20 (3pt)		0.155					
C40-20 (3pt)		0.164	0.160290985	0.004840893	2.348904092	42.76116298	1.728650325

B9. Tukey's HSD and Confidenc Intervals calculated at 95% using R Stats

	diff	lwr	upr	p adj
C40-40(2pt)(P)-C40-20(2pt)(P)	0.133051	-0.18784	0.4539392	0.8894068
C40-20(3pt)-C40-20(2pt)(P)	0.546218	0.22533	0.8671057	0.0002353
C40-20(3pt)(P)-C40-20(2pt)(P)	0.769472	0.448584	1.0903601	0.0000017
C40-20(2pt)-C40-20(2pt)(P)	0.818191	0.497303	1.1390788	0.0000007
C40-00(P)-C40-20(2pt)(P)	0.960727	0.639839	1.2816146	0
C40-40(2pt)-C40-20(2pt)(P)	0.975641	0.654753	1.2965293	0
C40-00-C40-20(2pt)(P)	1.101513	0.780625	1.4224011	0
MagC-C40-20(2pt)(P)	1.116193	0.795305	1.4370806	0
MagC(P)-C40-20(2pt)(P)	1.605099	1.284211	1.9259867	0
C40-20(3pt)-C40-40(2pt)(P)	0.413167	0.092279	0.7340544	0.0057317
C40-20(3pt)(P)-C40-40(2pt)(P)	0.636421	0.315533	0.9573088	0.0000297
C40-20(2pt)-C40-40(2pt)(P)	0.68514	0.364252	1.0060274	0.0000102
C40-00(P)-C40-40(2pt)(P)	0.827675	0.506787	1.1485632	0.0000005
C40-40(2pt)-C40-40(2pt)(P)	0.84259	0.521702	1.163478	0.0000004
C40-00-C40-40(2pt)(P)	0.968462	0.647574	1.2893498	0
MagC-C40-40(2pt)(P)	0.983141	0.662253	1.3040293	0
MagC(P)-C40-40(2pt)(P)	1.472047	1.15116	1.7929353	0
C40-20(3pt)(P)-C40-20(3pt)	0.223254	-0.09763	0.5441423	0.3426008
C40-20(2pt)-C40-20(3pt)	0.271973	-0.04891	0.5928609	0.1416078
C40-00(P)-C40-20(3pt)	0.414509	0.093621	0.7353967	0.0055491
C40-40(2pt)-C40-20(3pt)	0.429424	0.108536	0.7503115	0.0038708
C40-00-C40-20(3pt)	0.555295	0.234407	0.8761833	0.0001902
MagC-C40-20(3pt)	0.569975	0.249087	0.8908628	0.000135
MagC(P)-C40-20(3pt)	1.058881	0.737993	1.3797688	0
C40-20(2pt)-C40-20(3pt)(P)	0.048719	-0.27217	0.3696066	0.9999042
C40-00(P)-C40-20(3pt)(P)	0.191254	-0.12963	0.5121424	0.540784
C40-40(2pt)-C40-20(3pt)(P)	0.206169	-0.11472	0.5270572	0.4434926
C40-00-C40-20(3pt)(P)	0.332041	0.011153	0.652929	0.0388765
MagC-C40-20(3pt)(P)	0.346721	0.025833	0.6676085	0.0277547
MagC(P)-C40-20(3pt)(P)	0.835627	0.514739	1.1565145	0.0000005
C40-00(P)-C40-20(2pt)	0.142536	-0.17835	0.4634237	0.8459112
C40-40(2pt)-C40-20(2pt)	0.157451	-0.16344	0.4783385	0.7631773
C40-00-C40-20(2pt)	0.283322	-0.03757	0.6042103	0.1124464
MagC-C40-20(2pt)	0.298002	-0.02289	0.6188898	0.0825637
MagC(P)-C40-20(2pt)	0.786908	0.46602	1.1077958	0.0000012
C40-40(2pt)-C40-00(P)	0.014915	-0.30597	0.3358027	1
C40-00-C40-00(P)	0.140787	-0.1801	0.4616745	0.8545154
MagC-C40-00(P)	0.155466	-0.16542	0.476354	0.7750481
MagC(P)-C40-00(P)	0.644372	0.323484	0.96526	0.0000248
C40-00-C40-40(2pt)	0.125872	-0.19502	0.4467597	0.9169645
MagC-C40-40(2pt)	0.140551	-0.18034	0.4614392	0.8556532
MagC(P)-C40-40(2pt)	0.629457	0.308569	0.9503453	0.0000347
MagC-C40-00	0.014679	-0.30621	0.3355674	1
MagC(P)-C40-00	0.503586	0.182698	0.8244734	0.0006474
MagC(P)-MagC	0.488906	0.168018	0.8097939	0.0009206

	MagC	C40-00	C40-20(2pt)	C40-40(2pt)	C40-20(3pt)	MagC(P)	C40-00(P)	C40-20(2pt)(P)	C40-40(2pt)(P)	C40-20(3pt)(P)
MagC		<0.05	N.S.	N.S.	<0.05	<0.05	N.S.	<0.05	<0.05	<0.05
C40-00	<0.05		N.S.	<0.05	<0.05	<0.05	N.S.	<0.05	N.S.	N.S.
C40-20(2pt)	N.S.	N.S.		N.S.	N.S.	<0.05	N.S.	<0.05	<0.05	N.S.
C40-40(2pt)	N.S.	<0.05	N.S.		<0.05	N.S.	N.S.	<0.05	<0.05	N.S.
C40-20(3pt)	<0.05	<0.05	N.S.	<0.05		<0.05	<0.05	<0.05	<0.05	N.S.
MagC(P)	<0.05	<0.05	<0.05	N.S.	<0.05		<0.05	<0.05	<0.05	<0.05
C40-00(P)	N.S.	N.S.	N.S.	N.S.	<0.05	N.S.		<0.05	<0.05	<0.05
C40-20(2pt)(P)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		N.S.	<0.05
C40-40(2pt)(P)	<0.05	N.S.	<0.05	<0.05	<0.05	<0.05	<0.05	N.S.		<0.05
C40-20(3pt)(P)	<0.05	N.S.	N.S.	N.S.	N.S.	<0.05	<0.05	<0.05	<0.05	

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